NUCLEONICS

SEPTEMBER · 1949

An International Journal for Techniques and Applications of Nuclear Science

Benefits from Atomic Energy... 4

Method of Measuring Disintegration Rate of Sodium-22...16

Production of C^{14} in a Nuclear Reactor...18
L. D. NORRIS and ARTHUR H. SNELL

Domestic Users of Isotopes...27

Speed of Operation of Geiger-Müller Counters...33
HENDRIK DEN HARTOG

Fast Pulse Amplifiers for Nuclear Research...48
W. C. ELMORE

Effect of Soft X-rays on Vitamins (Niacin, Riboflavin, and Ascorbic Acid)...56
BERNARD E. PROCTOR and SAMUEL E. GOLDBLITH

Retention of Radon by the Mouse—I...63
JOANNE W. HOLLCROFT and EGON LORENZ

Alpha-Particle Detection with Dental X-ray Film...72
CARL C. SMITH

Lebensform für das Monitor...74
EVAN C. EVANS, III

Selected List of Documents for Industry...75

EDITORIAL....2 BOOKS....77
NUCLEONIC EVENTS....78 PRODUCTS AND MATERIALS....84

EDITORIAL STAFF—NORMAN R. BEERS, Editor; Jerome D. Luntz, Ethel Pelzer, Assistant Editors; George Doying, Gladys Montgomery, Washington Bureau; Keith Henney, S. D. Kirkpatrick, P. W. Swain, Consulting Editors

BUSINESS DEPT.—H. W. MATEER, Publisher; WALLACE B. BLOOD, Manager; D. H. Miller, H. R. Denmead, Jr., New York; Wm. S. Hodgkinson, New England; Warren W. Shew, Philadelphia; C. D. Wardner, Chicago; J. L. Phillips, Cleveland; J. W. Otterson, San Francisco; Carl W. Dysinger, Los Angeles; Ralph C. Maultsby, Atlanta; J. E. Blackburn, Jr., Director of Circulation

NUCLEONICS (with which is consolidated "Atomic Power" and "Atomic Engineering"), September, 1949, Vol. 5, No. 3, Publication Office: 212 East York St., York, Pa. Editorial and Circulation Offices: 330 W. 42nd Street, New York 18, N. Y. Published monthly by McGraw-Hill Publishing Company, Inc. Entered as second class matter December 17, 1947, in the Post Office at York, Pa., under the act of March 3, 1879.

Copyright 1949 by McGraw-Hill Publishing Company, Inc. All rights reserved. James J. McGraw, Jr., President; Eugene Duffield, Senior Vice President, Publications Division; Curtis W. McGraw, Vice President and Treasurer; Nelson Bond, Vice President and Director of Advertising; J. A. Gerardi, Secretary; J. E. Blackburn, Jr., Vice President and Director of Circulation.

Allow at least ten days for change of address. All communications about subscriptions should be addressed to Director of Circulation, 330 W. 42nd St., New York 18, N. Y. Price per copy $1. Subscription rates: United States and U. S. Possessions $10 for 1 year, $16 for 2 years, $20 for 3 years. Canada $15 a year. Latin America $20 a year. All other countries $25 a year. Return postage guaranteed. Member A.B.P. Member A.B.C.

The Atomic Industry and Human Ecology

II—ON RISK

THE CHANCE OF LOSS OR RISK confronts every man every moment of his life. This fundamental fact was evident from the first, and is unchanged by the advent of atomic energy. The numerical measure of risk on the other hand is variable, even in the *law of large numbers*, as any motorist knows who has found the premium on his car insurance jumped when he changes residence from one region to another where drivers are statistically worse. Whether nuclear fission introduced an epoch in which the hazard to daily living is greater or less is not yet determined by complete experience. NUCLEONICS believes from a first-principles analysis that the risk has decreased for society as a whole; and that this decrease will be reflected in greater life expectation through early applications in biology and medicine, increased industrial productivity, and more leisure hours for man.

It is recorded in history that each great scientific and engineering advance has been followed by an overall better health of the people. But each such advance has also been accompanied (and frequently followed) by far greater risk for a few. These few are exposed to greater risk sometimes through carelessness, often through ignorance, and not infrequently through their devotion to progress. Nothing can be done, for example, to reduce the hazards of testing new fighter aircraft to the level of a nonhazardous occupation. In fact the test pilot carefully provokes fate in present flight to decrease the hazards of future flight. A similar provocation of fate was not unknown among early atomic scientists. Some of them have suffered injury. And in one case at least, according to a recent press release, an accident compensation claim based on sight damage due to radiation was approved. There is now, however, little or no excuse for looking into a cyclotron beam, or any other beam of high energy radiation. Any claims for future injury would surely be more concerned with negligence than with ignorance.

Creation of a hazard, no matter how minute, for the few working directly with the development is quite different from the creation of a hazard for the public. D'Alembert in his essay, "Sur l'application du calcul des probabilités à l'inoculation de la petite vérole (smallpox)," points out for example that the community would gain on the average if, by sacrificing the lives of one in five of its citizens, it could ensure the health of the rest, but he argues that no legislator could have the right to order such a sacrifice. Irrespective of one's moral ethics in this matter, it is hard to disagree with a statement by the late Lord Keynes that "The hope of a very favorable outcome, which may balance the risk in the mind of the borrower [*atomic scientist*], is not available to solace the lender [*public*]." (Italics are the Editor's.)

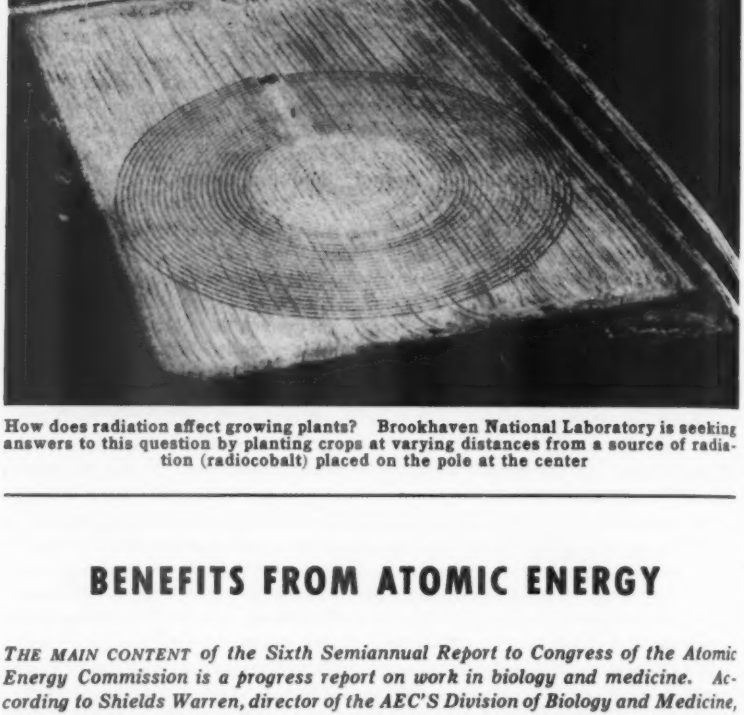
Just as test flying new aircraft over Manhattan is prohibited, by common sense if nothing more, so must any action on the part of scientists and engineers which increases the risk of daily living for those "outside the project" be prohibited. More than that. Since laws are formulated by legislative bodies usually after the event, atomic scientists themselves must establish and maintain procedures which are safe for the public. Their success in self-restraint is obvious from the record, and it is an especially commendable success in the light of public apathy to other equal or greater hazards of modern civilization. The vitally important matter is that past successes and failures be understood by scientists and informed public alike so that complacency will never replace alert caution.

Such understanding in fact partially determines the numerical measure of the risks, from a practical point of view at least. Colonel Cooney writing in *Radiology* recently says, for example, that for battle discipline and military effectiveness the dominant measure is not the hazard itself but the soldier's estimate of the hazard. He cites "unfortunate psychological reactions" which have developed in the minds of both the military and civilians. These reactions are not improved by the display sometimes given facts or inferences out of context. Both in the popular and in the technical press one notes a tendency to emotion. Perfection demanded to meet the statement, "As for health hazards to the consumer, there must be none," is impossible. It is fine to aim at perfection but dangerous to claim its attainment even if only in public. The facts are liable to become known and to prove embarrassing.

NUCLEONICS believes that factual and early discussion of the risks involved in all phases of the atomic industry is desirable. Even press and radio "warnings" have served very usefully, in quick notice of the risk in breaking tubes containing beryllium for example. More recently, according to one newspaper, serious radiation hazards exist in devices being distributed commercially to eliminate static through employment of thin strips of polonium.

For those directly employed in work with radioactive substances or in the neighborhood of high-energy radiation from the various machines, special devices are constructed and precautions taken to minimize the hazards of their work. Shields placed between source of radiation and the individual effectively reduce the radiation dosage so that one may remain in that neighborhood for a *specified length of time*. Special gloves, syringes, hoods, stirrers, *etc.*, serve not only to lessen the risk of laboratory work but also to illustrate how great is the need for additional remote control gadgetry. Basic research is needed too. One of the most fertile fields concerns itself with the effects of small particles, both alone and when inhaled with various gases, hydrogen fluoride for example. There is some suggestion that Los Angeles "smog" may in fact be determined not by one element but by the coexistence of two or more substances.

New developments have invoked new hazards and various reactions from indignation to overconfidence in the good expected through many generations and among many people. Charles Kettering once remarked that some "bankers regard research as most dangerous and a thing that makes banking hazardous due to the rapid changes it brings about in industry." Such an excess of caution has never been and will never be typical in a healthy and vigorous civilization.



How does radiation affect growing plants? Brookhaven National Laboratory is seeking answers to this question by planting crops at varying distances from a source of radiation (radiocobalt) placed on the pole at the center

BENEFITS FROM ATOMIC ENERGY

THE MAIN CONTENT of the Sixth Semiannual Report to Congress of the Atomic Energy Commission is a progress report on work in biology and medicine. According to Shields Warren, director of the AEC'S Division of Biology and Medicine, "The work described in this report represents only a small part of the large body of knowledge which we are certain will result from these studies. Such studies probably will require from five to ten years or longer for full fruition." NUCLEONICS presents below excerpts from one of the important sections of the report.

THE BODY'S BUILDING BLOCKS

The body, in its functioning, uses a variety of building blocks. *Proteins*—complex molecules manufactured in the body from amino acids. The enzymes, catalysts of cellular reactions and some hormones also are proteins, proteins are required to bind vitamins into useful compounds. *Carbohydrates*, essential fuels for the body, are burned to produce energy and maintain life and also enter importantly into body structure. *Lipids*—the fats and fatlike substances, which are at once a source of energy, a tool of regeneration and a component of certain hormones. *Nucleic acids*, whose composition is only partly understood, are tied in a way not yet explained to a protein that has not yet been defined, to form the largest molecules of all, the nucleoproteins, making up the nuclei of the cells that form the substance of the body.

In addition to these building blocks, other important key substances include

the various *blood* constituents and the *electrolytes*—such minerals as potassium, sodium, and calcium.

Full understanding of the hows and whys of the behavior of many of these substances must often wait on determining exactly what they are. Diseases, or radiation, shatter some of these substances, alter others, render some incapable of functioning. This also will be difficult to understand—and consequently hard to prevent or treat—until the basic nature and activity of lipids, proteins, nucleic acids, electrolytes, enzymes, and hormones are better defined by basic research.

Blood

An example of the attack upon these problems is the studies on the essential constituents in the blood. The blood, containing plasma and cells, is the circulating distributor of chemicals and oxygen throughout the body. It lends itself to biochemical study because of the ease of obtaining samples.

Study of Anemia

Anemia is a disease characterized by a deficiency in the quality or quantity of the blood. Dosages of iron often correct the deficiency, but certain types of anemia do not yield to this treatment. Occasionally this type is caused by a failure of the pituitary gland, located just beneath the brain, to secrete enough of its essential growth hormone.

Treatment with hormones has been found to correct all phases of anemia in the pituitary cases except for the deficiency in the hemoglobin—the coloring matter of the red corpuscles which transmits oxygen to the cells and carries away the oxidation waste products to the lungs, and which uses iron as one of its constituents. At Boston University, scientists of the School of Medicine removed the pituitary gland of laboratory rats, injected the radioactive iron, then traced the distribution of the iron through their organs and bodies and compared this distribution with that of normal rats. They concluded that the hemoglobin deficiency was not caused by lack of iron.

The scientists therefore pushed their experiment into the other constituents of hemoglobin—in particular the protein fraction. They found that by feeding the rats a high protein diet, coupled with hormone therapy, they could prevent anemia even after removal of the pituitary gland. Accordingly, they are now preparing to use radioactive carbon to label glycine, one of the amino acids used by the body to manufacture the hemoglobin protein, to trace this phase of blood metabolism.

The scientists feel that their investigation has reached a stage which will permit them to try this treatment on human patients in the clinics. High protein diet added to present hormone therapy, they suggest, may succeed in overcoming anemias that do not yield to iron treatment.

Measuring Body Liquids

At the Radiation Laboratory, University of California, red blood cells are taken from the body, labeled with radiophosphorus and then reinjected to determine the speed with which the labeled substance mixes with the total blood. The time for complete mixing varies widely with individuals, it was found, and requires between 5 and 15 minutes. The interval was definitely longer in patients with heart diseases. The rate of disappearance of sodium and iodine from the blood stream, as compared with the total surface of tissue was measured by tracers. These two investigations will make possible a satisfactory measurement of such factors as blood volume, the amount of fluid outside of cells, total body water and total body sodium.

Metals in Blood Metabolism

Iron and zinc both enter importantly into the metabolism of red and white blood cells. Discovering the activity of these "trace" metals therefore may offer important information both in anemia and in leukemia.

A group of physicists, chemists, and physicians, collaborating in studies of these diseases at the Massachusetts Institute of Technology since 1941, is currently using radioisotopes of iron and zinc in its work under a contract with the AEC.

Measurements of iron in the human system, by means of the radioactive isotopes, show that the body loses only a very small fraction of this metal and that the daily requirement is only about one to two one-thousandths of a gram, but even under forced feeding the system assimilates very little. However, the human system salvages about 90 to 95 percent of the iron when red cells die and reuses this iron to form new cells.

Experiments have also shown that new red cells in the bone marrow can assimilate iron for a few days, but that mature red cells cannot. Folic acid and liver extracts increase the ability of the young cells to take up iron.

At Brookhaven National Laboratory, scientists have determined that iron, an important constituent of the red blood cells, is used in almost equal amounts by another body pigment, the cytochrome, and that even larger quantities are used by a constituent of the muscles suspected to be the muscle hemoglobin.

In the experiments at M. I. T. with zinc, scientists found that this metal apparently plays an important role in the life cycle of the white blood cell. Large quantities of living white cells, tagged with radiozinc, are being injected into dogs in an effort to trace this life cycle. A full understanding of the process may throw some light on the mechanism of overproduction of white cells in leukemia. They have demonstrated that leukemic white blood cells have a pronounced deficiency in zinc.

Using radioactive metals to follow "trace" elements, Harvard Medical School scientists have found that chromium enters into many tissues of the body. It penetrates blood cells within a matter of minutes, and stays firmly bound, possibly for the life of the cell. A program under way now is seeking to determine which cells and, if possible, what portion of each cell the chromium enters. Other research is tracing the function of calcium in the nerves, and the role of zinc in insulin formation.

Proteins in Blood Stream

The proteins of the blood assist in blood clotting, form a part of the hemoglobin molecule, hold fluid in the blood vessels, and are a part of the body's defenses against infection.

At the University of Rochester, scientists used radiocarbon to label one of the amino acids, lysine, which is indispensable to life and growth. By tracing the labeled lysine, it was discovered that the body used it to form other amino acids, to build other proteins of the blood plasma, and to build red corpuscles.

As a result of the studies, other scientists suggest that labeled red cells be used to test methods of handling and storing whole blood for transfusions.

Further studies showed that, in the dogs used in the laboratory, plasma proteins have a very rapid turnover. About half the protein in the dog's plasma system is renewed within 3 days. This suggests that plasma proteins play a very important part in the entire protein economy of the body, and they may represent preformed "building blocks" used for tissue. Scientists are now using tracer-proteins to discover what happens to these protein molecules in a plasma transfusion.

Study of Loss of Body Salts

Electrolytes, the mineral salts essential to health and to many body processes, often are lost rapidly after severe injury, surgical operations or generalized severe infection. These changes in body chemistry are of the greatest importance to survival, healing and convalescence.

Studies in this field during the last 2 years at Harvard Medical School, Peter Bent Brigham Hospital and Massachusetts General Hospital have concentrated on cells' loss of potassium and an apparent penetration of sodium into the cells, although sodium is normally found only outside of cells.

Radioisotopes are used in two ways in this clinical research. Radiopotassium has been used to determine that people may lose up to 25 percent of total body potassium after severe surgery. Radiosodium is also being injected before operation in certain cases, so as to measure the amount that is retained in the body fluids. This will indicate the amount that has been absorbed into the cells.

A nonradioactive variety of water—heavy water—has been used in this same group of experiments to determine, by an isotope dilution method similar to that used with potassium, the amount of water in the body. The method is much more difficult since the experimenters are unable to use the radioactive counter, and must determine the presence of heavy water by extremely delicate and accurate tests. They have calculated that the amount of water varies widely with the body. The method is much more difficult since the experimenters of fat. The total amount of water may range anywhere from 60 to 80 percent of total body weight.

Scientists at Bowman Gray School of Medicine, Wake Forest College, are using radioactive sodium and potassium to study the effects upon the organs of

Corn grown from seed exposed to atomic bomb at Bikini shows effects of irradiation, in tests at the California Institute of Technology. Three young plants show stunted growth

such infectious diseases as Rocky Mountain Spotted Fever. In this disease, the membranes of blood vessels and individual cells are so affected that water and salt can pass through them more readily than in normal individuals. In severe infections, even proteins and red blood corpuscles can pass through the membranes. Standard techniques in this research have given only limited information. The use of radiotracers may yield more detailed information.

Proteins

The way in which proteins—the substance of the structure and the engines of the body—are formed has long been hidden. Synthesis has been observed hitherto only in the living animal or plant. To learn how the process occurs investigators must be able to make the process go on outside the body in reaction vessels. A project at California Institute of Technology succeeded in producing protein synthesis outside the body in glass receptacles. Rabbit bone marrow cells, rat diaphragm, and guinea pig liver were used. All three tissues take up a number of different amino acids, among them glycine, leucine, and lysine which are building blocks of proteins. Since each of these acids has been tagged with radiocarbon, the protein molecules formed are labeled in three places. This fact helps to locate the position of other amino acids and to work out a detailed pattern of amino acids in

How plants grow and make use of nutrient material is being studied with tracers by the Department of Agriculture. Photo shows plants being dissected to find how radioactive material has been distributed in leaves, stems, roots, and other parts during growth

protein. It is variation in pattern which underlies such differences as antibody behavior, structure, and catalytic activity.

It was found that the incorporation of amino acids into the proteins of these tissues can be made to proceed outside the body at the same rates and under similar physiological conditions as within the body. The process requires energy obtained from the burning of food materials.

Radiocarbon is being used at Oregon State College to trace the relationship of carbohydrates to amino acids, and further to attempt to determine whether as is believed, certain amino acids are related to the water-soluble vitamin, pantothenic acid, which is the "anti-gray hair" part of the vitamin B complex.

Lipids

The lipids include fats and fat-like substance formed in the body from the food we eat; it is their "combustion" that supplies a good part of the body's energy. An understanding of the way the lipids are formed and broken down into the products that are "burned" by oxidation for energy and of the effect upon this process of certain drugs and diseases is of the utmost importance to a clear picture of human life processes. It has particular importance to people suffering from diabetes.

Radiophosphorus is used at Bowman Gray School of Medicine, Wake Forest College, to study the formation of certain liver fats which contain phosphorus. A number of powerful drugs failed to affect the process appreciably, though some reduction in the formation of the fats resulted from slowing thyroid activity. Apparently, the liver has the power to continue production of these fats under very adverse conditions. However, very marked decreases were observed after administration of compounds which presumably reduce the availability of the fat-building materials. The drugs also are being used to clarify the exact pathways through which the phosphorus fats are formed in the liver.

These processes may be important for understanding the causes of certain liver diseases, and the formation of the phosphorus fats in the blood is being studied in human patients.

In another study, the harmful effects of radioactive phosphorus are being investigated to find out whether changes in diet may increase the resistance of animals to the harmful effects of internally administered radioactive elements.

Nucleic Acid Molecules

The normal functioning of the cell and of the entire living body depends upon a very carefully balanced working relationship among the various biological factors previously discussed. If we were to select one type of compound which could be designated as the keystone of life, nucleic acids and nucleoproteins would be the leading candidates for the honor. Nucleic acids are composed of simple organic nitrogen ring compounds, sugar molecules, and phosphorus groups, linked together into chains to form very com-

plex supermolecules. These nucleic acid supermolecules in turn are linked to protein supermolecules to form nucleoprotein.

The nucleoprotein molecule is at the borderline between the truly living material and the nonliving. Certain of the plant and animal viruses are known to be pure nucleoproteins. The chromosomes which control the hereditary characteristics of the individual and the race are nucleoproteins. Our present knowledge of the cancer problem indicates that abnormal influences may cause the nucleoprotein material in the cell to go wild and to reproduce itself in an uncontrollable manner.

Program on Nucleic Proteins

In order to increase our scientific understanding of nucleoproteins and how they are affected by radiation, the Commission is sponsoring an extensive program, in its own and university laboratories, to synthesize the various building blocks of the nucleoproteins, to label them with radioactive isotopes and to follow their metabolic course in animals and other living organisms. It is only when we know precisely how these building blocks are put together and how their structure is altered by radiation and disease that we will be able to proceed soundly in the treatment of radiation effects.

Research men at the University of Colorado are studying the activity of derivatives of nucleic acid in the system.

Many of the research projects in other areas are related to the elements of the cell nucleus. At Harvard Medical School, for example, the effects of adrenal and pituitary hormones and of insulin in the formation of starch in muscle cells and its release through the action of acetic and pyruvic acid are being studied.

Study of Diabetic Processes

Ever since the discovery of insulin as a control for diabetes, attempts have been made to learn exactly which chemical reactions in the body are speeded up or slowed down by this substance. The primary chemical disturbance caused by undersecretion of insulin is, of course, a reduction in the body's ability to use sugar.

At Harvard Medical School radiosugar was made by growing bean plants in an atmosphere of radiocarbon dioxide or by using liver cells for a similar process of synthesis. This sugar, and the interaction of insulin, were then used in studying the chemistry of the muscle cells of rats which were diabetic, or which had hormone-secreting glands, the pituitary or the adrenals, removed.

These experiments showed that insulin increases the ability of the muscle not only to manufacture glycogen—the form in which sugar is stored in the cells—but also to burn sugar for energy.

Further experiments have probed into the acid processes of diabetes. Acetic and pyruvic acids are formed momentarily when fats and sugars are burned in the body. By tagging these acids with radioisotopes, it was found their use is decreased in the muscle cells of a diabetic. Insulin brought back to normal the use of pyruvic acid, but acetic acid remained unburned. If the factor responsible for burning acetic acid—the factor missing, or greatly reduced in the diabetic—can be found and made available, the treatment of diabetes will be further improved.

Other Studies in Metabolism

By injecting into mice the B–2 vitamin as radioactive nicotinic acid or nicotinamide, scientists at Los Alamos Scientific Laboratory have shown that there is no essential difference in the way the body uses the two. Both are synthesized into Coenzymes I and II, substances into which nucleic acid splits when it breaks down. Incubation of the two vitamins with blood

showed that, whereas nicotinic acid could be directly used by the red blood cells, nicotinamide could not, which may help explain why the latter is better in intravenous treatment.

The drug thiourea used in treatment of an overactive thyroid gland, was rendered radioactive and used to trace the drug's activity. After 72 hours, it was found that the concentration of thiourea in the thyroid was 80 percent greater than in other tissues.

Radioactive phosphorus is used as a tracer at Brookhaven National Laboratory to study its part in metabolism of sugars in the body. A great deal of work in this field has resulted in formulating what is known as the "phosphorylation cycle"—a description of the various intermediate steps in which phosphorus compounds are formed and used in the conversion of sugars into energy. Present experiments are concentrating on the liver's use of phosphorus in sugar metabolism. Normal conditions will be investigated first, afterwards those which exist in diabetic and cancer patients.

There is also some evidence that exposure to radiation reduces the capacity of the body cells to combine sugar derivatives with phosphate, and this will be investigated further.

DIAGNOSIS AND TREATMENT

In addition to serving as a tool for basic research into life processes, radioisotopes have proved valuable in laboratory and clinical studies of diseases, and are being used also in diagnosis and in treatment.

Isotopes In Diagnosis

Some of the most dramatic and striking results in medicine today are obtained from treatment to correct under- or over-secretion by the thyroid and the sex glands.

In diagnosing illnesses resulting from lack of hormones, extremely delicate techniques are necessary since these substances are effective in dilutions of one part in 10 million. Radio-tagged elements are used at Yale University School of Medicine, in connection with microscopic methods, to measure secretion of the sex hormones; radioiodine in the case of the thyroid. In one case, a half teaspoonful of human serum was flown from California to Connecticut for a test and confirmed the diagnosis of overactive thyroid more quickly than routine methods on the scene, in San Francisco.

Locating Tumor in Surgery

Radiophosphorus is being used at Harvard Medical School to locate brain tumors during surgery. Experiments showed that brain tumors, following intravenous injection, absorbed many times as much phosphorus as the normal brain tissue—in some cases over 100 times as much. The rays emitted by the radiophosphorus, however, penetrate only a little more than one-quarter of an inch through brain tissue. Thus, in locating the tumor, it was necessary to have a counter small enough to be inserted into the brain during surgery. Such an instrument was being devised in the Physics Department of the University of Wisconsin, and it was almost ready for use at the time that the technique was first hit upon.

The combination of radiophosphorus injection and this tiny counter, has been used successfully in 14 operations to remove brain tumors.

Isotopes in Treatment

Radioactive iodine has been used in the treatment of Graves' disease (exophthalmic goiter) in which the thyroid gland is overactive. There are other means of treatment in these cases, including surgery to remove the gland. Radioiodine treatment is effective because the iodine has an affinity for thyroid tissue and the radioactive iso-

tope, deposited in the gland, depresses its activity by the effect of the radiation. It is often useful where surgery has been unsuccessful and the gland has recurred after operation. Studies supported by the Commission at the Memorial Hospital, Yale University, University of California and the Columbia University College of Physicians and Surgeons have verified this means of treatment.

Easing Heart Pains

Radioactive iodine also is being used at Harvard University to relieve pain and distress in two types of heart disease—angina pectoris and congestive heart failure. Previous studies showed that lessening of thyroid activity would so diminish the body's demands upon the heart as to reduce markedly the choking sensations and pain of angina pectoris and the shortness of breath and dropsy of congestive heart failure. Useful in a small percentage of cases that do not yield to other therapy, treatment to reduce the activity of the thyroid by use of radioiodine has been tried on 19 patients. In five of nine suffering from angina pectoris, the pain was strikingly lessened or abolished and several are now gainfully employed. In four of seven patients with congestive heart failure, shortness of breath has been alleviated and ability to work increased. When thyroid deficiency is too marked, small dosages of thyroid substance improved the condition of patients. This treatment still needs further investigation.

CANCER PROGRAM

Radiocobalt and Cancer

The value of radiocobalt in cancer research and treatment is being determined. In treatment, radiocobalt is used as a substitute for radium which is one of the established tools for destroying cancer cells.

Radiocobalt gives off radiation that is very much the same as that of radium in its effects, but a milligram of cobalt 60 will produce less radiation than the same amount of radium. Scientists have evaluated this difference between the two elements on a theoretical and experimental basis. Their findings have made it possible to try out special techniques for the use and handling of radiocobalt to test its worth in treating cancer.

In certain types of applicators for cancer treatment, radiocobalt has a positive advantage over radium. In using radium, physicians typically may imbed it in a wax form modeled to fit the inside of the mouth, the outside of the jaw, or the cervix. The pattern in which radioactive seeds are placed in the form is extremely important. The radiologist tries to meter the dosage, by his placing of the seeds, so that cancerous areas receive the correct radiation and so that the applicator will create no "hot spots" to cause serious local over-exposure.

Radiocobalt vs. Radium

Difficulties arise in such treatments with radium both because of its cost and the fact that radium is usually contained in nonpliable tubes. On the other hand, radiocobalt is relatively cheap to produce and can be used in any reasonable quantities. It can be made up in various pliable shapes with different rates of radioactivity. These factors combine to make it easier to distribute properly in such a wax form.

Another advantage of cobalt is that it can be prefabricated in an ordinary laboratory before it is irradiated. Even after being made radioactive, it can be stored with proper protection as a fine wire on a spool and clipped off in desired quantities as needed. It also can be made in an alloy form with nickel to improve its metallurgical properties.

Where costs are concerned, the price

of radium is between $15,000 and $20,000 a gram, whereas radiocobalt can be had at a minimal charge for handling. However, radium is, for all practical purposes, of permanent value to an institution, since it requires 1,500 years to lose half its radioactive strength. By contrast, radiocobalt has a half-life of 5 years. This comparatively rapid decay also makes it necessary to measure the radiation of a quantity of cobalt 60 before application.

From another viewpoint, radiocobalt has a further advantage. Radium is very dangerous if accidentally set free in the body, since it remains in the body and continues to destroy tissue for many years. Cobalt, on the other hand, is rapidly excreted.

In general, any medical institution properly staffed and equipped to handle radium is in an excellent position to make use of radioactive cobalt. Radiologists do not believe that radiocobalt should be used by institutions not fully qualified for radium handling since the cobalt, like radium, can be dangerous. Precautions should be essentially the same for both materials. Cobalt, however, does have two additional advantages. It is magnetic and consequently may be handled with electromagnetic holders at some distance from the hands or body so as to reduce exposure to its radiations. Moreover, the energy of beta particles emitted by cobalt is considerably less than that of the alpha particles from radium, and this simplifies the shielding problem substantially.

Research Using Radiocobalt

Exposure of animals to radiocobalt radiation at Ohio State University indicated that the effects were similar, if not identical, to those expected from other radiation sources such as radium. Methods of safe handling were developed so that applicators could be used on human patients without excessive exposure of the technical staff to radiation.

In limited usage, during the last 9 months, cases were treated which otherwise could not have been successfully irradiated with the means at the university's disposal. Where a cancer-killing dosage was administered, the tumor died. In some cases, only temporary arrest of the disease could be expected because of the amount and area involved, but the arrest was accomplished. About 15 cases of 5 general types of cancer have been treated and no untoward effects observed.

Indications are that, due to the flexibility and comparative safety of radiocobalt, the university will be able to achieve its original objective of better treatment of cancer. Evaluation of results will require further large scale work and some years of time.

Use of activation analysis by the University of California Radiation Laboratory showed that the amount of cobalt distributed in the entire human body is about a half microgram—a mere trace. It enters the nucleus of certain tissue cells and, normally, the half-life time of its loss from the body is about one day. However, in mice with cancer of the breast, approximately twice the normal amount of cobalt was taken up by liver cells and, at a later time, appeared in the nuclei of cancer cells.

A radiation exposure chamber, using cobalt 60, as a source of rays to test their effect upon laboratory animals, is nearing completion at the University of Illinois. The cell, using about 6 curies of cobalt 60, can administer very low to fairly high dosages to mice. It cannot handle any animal larger than a rat but will be capable of 4,500 roentgen units of radiation per hour—some nine times the estimated lethal dosage for man.

The exposure chamber is an important instrument for testing radiation effects upon living animals and will add to an understanding of cobalt 60 in cancer treatment.

The University of Illinois experiment, besides testing the radiation effects, will assist in designing applicators to fit particular needs in cancer therapy.

Cancer Research Projects

Cancer research, sponsored by the Commission, has a dual purpose. It seeks to learn the basic structure and processes of cells—for cancer is preeminently a disease of the cell—and methods of using radioisotopes to diagnose cancer and to destroy tumors. It has the further purpose of studying radiation effects in man since in cancer patients heavy irradiation can be studied more intensively and with greater justification than under any other circumstances short of war and accidents.

A great deal of basic research is essential to a solution of the cancer problem. In trying to understand the subtleties of cancer cell behavior, we must have a firm understanding of the normal cells.

Knowledge of the details of nucleic acid metabolism should provide better means for combating, for measuring, and for enhancing the effects of radiation.

The simpler organic components that enter into the formation of nucleic acid have been prepared in the laboratory at Memorial Hospital, Sloan-Kettering Institute, and labeled with isotopes. Radiocarbon (C^{14}) has been used, and the nonradioactive heavy isotopes of nitrogen and carbon. These components are then fed to animals to ascertain which compounds in what amounts go to normal cells as well as to cancerous tissue.

No tissue can grow without increasing its mass of protein, which is incorporated into cell structure. Control over growth, as in a cancer tumor, requires an understanding of this continuous process of building up and breaking down proteins. In normal, nongrowing tissue, the process is in delicate balance. In cancer, the building process is excessive. A considerable amount is known about the enzymes that break down proteins, but little, until recently, about the opposite process.

At Huntington Memorial Hospital, tissue slices were incubated with radiocarbon—tagged amino acids—the basic stuff of which proteins are formed. The acids were taken up in the protein of the tissues, but it was found that two factors would stop the process: the absence of oxygen, or the addition of minute amounts of dinitrophenol—a drug known to prevent the formation of energy-rich phosphate bonds, once used clinically to help in weight reduction. Slices of tissue from the cancerous livers of rats take up one of the amino acids—alanine—six times as fast as normal liver.

Radiation can cause cancer as well as control it, and this effect requires full study. A great number of experiments undertaken at Argonne, Oak Ridge, and the National Cancer Institute, to determine what levels of radioactivity and isotopes may be considered safe for workers in the atomic energy field, have been useful in helping to understand how cancer arises. Argonne is trying to discover whether radiation produces cancer by chemical or other types of injury to the cell.

Experimenters are irradiating normal chemicals of the body to find whether they form cancer-producing chemicals. They are separating out microscopic parts of cells and using the electron microscope to look for changes caused in them by radiation. One puzzling question is the considerable time which elapses between radiation and the appearance of cancer. Tissues and cells are being examined carefully for chemical and structural changes which must occur during this period, but which are invisible by ordinary means

of examination. For example, the changes in the lens of the eye resulting from neutron exposure might be missed in tissues, such as muscle, which are not transparent. Low-level radiation is being studied by subjecting normal body chemicals and cells to neutrons from the nuclear reactors.

The way in which the metal beryllium, now coming into larger industrial uses, causes cancer of the bone was studied by injecting beryllium into rabbits at Huntington Memorial Hospital. A group of enzymes, called phosphatases and extremely important to bone growth, are normally accelerated by magnesium—an element that closely resembles beryllium. Beryllium, on the other hand, inhibits the action of the enzymes. The experiments suggest that the enzyme is "fooled" into taking on beryllium instead of magnesium, and then is prevented from performing its normal function. Further studies will seek to clarify the relationship of these two elements and of calcium to other enzymes.

Other experiments are directed toward learning more about the effects of some isotopes which can be valuable in treatment of disease, but which are also dangerous because of the way in which the body stores them. The best example of such an isotope, potentially both dangerous and of enormous value, is carbon 14. Since the half-life of this carbon is about 5,000 years, its prolonged retention in the body might cause cancer.

The permissible exposure of living organisms to the radiation from various compounds of radiocarbon is being investigated at Argonne, Southern Research Institute, and the Universities of Minnesota and California. Carbon enters into all the organs and tissue of the body and is a prime research tool, but research using radiocarbon is limited at present to animals. In the case of radioactive sodium bicarbonate, or of inhaled carbon dioxide gas, it has been learned that the radiation hazard is probably not as great as had been expected. Workers at Southern Research Institute are looking for other forms in which radiocarbon may be used in human patients and have combined it into urea, ethyl alcohol, and urethane, substances of interest in cancer study.

Isotope Treatment of Cancer

In using radioactive isotopes to treat cancer, physicians seek to destroy the growth by placing a source of radiation within the malignant cells themselves. If they can concentrate the radiation in this way with high efficiency, the patient will suffer less general radiation exposure than from typical treatment by X-ray or radium. High efficiency is possible only if a tumor readily and rapidly absorbs the radioisotope, and if the rest of the patient's body takes up only harmless amounts.

Cancers vary widely in type. One tumor may absorb a radioisotope of one type with avidity, another may not take it up at all. So far, physicians have been most successful in using radioiodine to treat cancers of the thyroid.

Radioiodine has definite advantages in treating cancer, but its use is sharply limited because normally it goes almost exclusively to the thyroid gland, or to cancers that have spread from this source. Scientists are attempting to direct radioiodine, and other isotopes such as radiosulfur, to other possible sites of cancer in the body. They do this by attaching the radioisotope to a "guide" that when injected into the system will go, for example, to the kidney. Research men prepared the "guide" by injecting mouse kidney tissue into a rat, then extracting from the rat the antibody which it built up to resist this alien material. When this

antibody is placed in a solution of the radioisotope, it will absorb a quantity of the radioactive material. Injected then into a mouse, the antibody "guided" large amounts of the isotope to the kidney with extraordinary speed. Guides have been similarly prepared which will carry radioiodine to the lung and this establishes that the principle of using a guide is not confined to a single tissue. Scientists at Sloan-Kettering hope similar guides may be prepared to carry radioisotopes to cancer tissue.

A compound, stilbamidine, known to localize in myeloma cells—cancerous cells of the bone marrow—has been synthesized with radiocarbon at the Radiation Laboratory, University of California. Since this type of cancer occurs only in humans, the use of this substance to guide radioactive material to cancer cells is awaiting clinical tests.

Other Isotope Treatment

Radiophosphorus is now a standard treatment for certain blood disorders. Its use at New England Deaconess Hospital, Western Reserve, University of California, Berkeley, and many other hospitals to treat leukemia and polycythemia indicates that most cases of polycythemia vera can be controlled by dosages of 2.5 to 5 millicurie of radiophosphorus as disodium phosphate, either by injection or by mouth. Cases of leukemia that have become resistant to X-ray treatment may be helped.

Experiments in embryo chickens to test the effect of this form of treatment on the bone marrow and other tissues indicates dosages much heavier than used in treatment were required to produce damage.

Radiophosphorus is absorbed by stomach tumors in human patients much more rapidly than by normal tissue, tests at Harvard University and Peter Bent Brigham Hospital showed. There was an increase of 124 percent in the turn-over of protein phosphorus in stomach cancer. The effects of stomach secretions on this process are being studied. The rapid absorption of protein phosphorus by other tumors such as those of the skin, has been studied at the University of California Medical School.

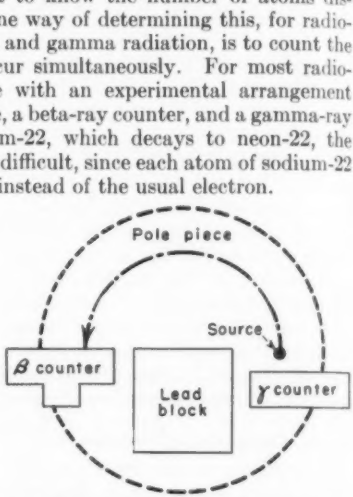
Methods of placing radioactive materials in the lymphatic system of the body, a medium through which cancer frequently spreads, have been devised at the Radiation Laboratory, University of California. Certain yttrium colloids, injected into a lymphatic vessel, spread uniformly through the network of lymph nodes above the injection. Patients with cancer will be treated experimentally by this method.

Physicians at the University of Chicago and Argonne Laboratory have been testing the value of radioactive arsenic in treating blood diseases and cancer. Nonradioactive arsenic is a useful drug in leukemia. It can be made radioactive by irradiation in the nuclear reactor, should it turn out that its value in treatment is increased by radioactivity.

METHOD OF MEASURING THE DISINTEGRATION RATE OF SODIUM-22

IN PREPARING STANDARDS of radioactivity and in using radioactive isotopes as biological tracers, it is important to know the number of atoms disintegrating in each unit of time. One way of determining this, for radioactive substances emitting both beta and gamma radiation, is to count the beta and gamma emissions that occur simultaneously. For most radioactive substances this can be done with an experimental arrangement consisting only of a radioactive source, a beta-ray counter, and a gamma-ray counter. But in the case of sodium-22, which decays to neon-22, the measurement problem becomes more difficult, since each atom of sodium-22 disintegrates by emitting a positron instead of the usual electron.

Positrons are very readily absorbed by matter and converted into a form of gamma radiation known as "annihilation radiation," and the gamma counter cannot distinguish this radiation from the nuclear gamma radiation which accompanies beta emission. In order to overcome this difficulty, J. L. Herson of the National Bureau of Standards has used a coincidence counting arrangement in which the beta and gamma counters are separated from each other by a lead block and placed in a moderate magnetic field. The radioactive source is placed near the gamma counter so that positrons emitted by the source will travel, under the influence of the magnetic field, in a semicircular path around the lead block to the beta counter. The lead block effectively prevents the annihilation radiation produced near the beta counter from reaching the gamma counter and causing false coincidences.

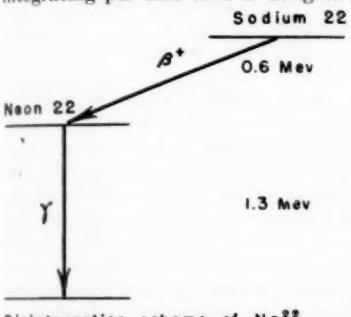


Coincidence counting arrangement

The problem of determining the relative number of nuclear and annihilation gamma rays reaching the gamma counter still remains since a small amount of annihilation radiation is produced near the radioactive source. This was taken into account in the work on sodium-22 at the Bureau of Standards by performing the experiment in four different ways. Gamma counting rates were determined using two different gamma counters, observing the gamma rates for each counter with and without an aluminum cover over the source. The two gamma counters were the same shape and size, differing principally in relative counting efficiency for low-energy radiation. The difference in efficiency was caused by using different outer electrode materials—copper in one counter, platinum in the other. The aluminum shield was placed over the source to increase the amount of annihilation radiation. The aluminum does not, however, appreciably affect the number of nuclear gamma rays reaching the counter.

The results of the four experiments yield the information needed to determine (1) the true counting rate for 1.3-Mev nuclear gamma rays, (2) the counting rate for 0.5-Mev annihilation gamma rays, (3) the relative efficiency of the two counters for 1.3-Mev nuclear gamma rays, and (4) the relative efficiency of the two counters for 0.5-Mev annihilation gamma rays.

The true nuclear gamma count combines with the beta count and the beta-gamma coincidence rate to make possible the computation of the absolute disintegration rate of sodium-22. If the number of atoms disintegrating per unit time is designated by N, the number of counts produced in the beta counter will be Np, where p is the probability of a beta ray entering the counter and being counted. Similarly the true number of nuclear gamma counts is represented by Nq, where q is the corrected probability obtained by using two gamma counters, each with and without an aluminum screen over the source. The probability of both the beta and gamma counters responding to radiation resulting from the disintegration of a single atom is then the product of the respective probabilities, so that the number of genuine coincidences per unit time is Npq. The counting rates Np, Nq, and Npq then give three equations in three unknowns, readily solved for the disintegration rate N as well as the probabilities p and q. The disintegration rate for the radioactive sodium chloride solution used in these experiments turned out to be 2.69×10^4 disintegrations per second per milliliter.



Disintegration scheme of Na^{22}

The efficiency of the platinum counter used in this work was found to be practically equal to that of the copper counter for 1.3-Mev gamma rays, but 2.9 times as large for 0.5-Mev annihilation radiation. When the source was covered with $\frac{1}{32}$-inch aluminum, the counting rate for annihilation quanta increased by 25%. When the copper-electrode counter was used to measure the radiation from sodium-22, about 70% of the total gamma counts were due to nuclear gamma rays and 30% to annihilation radiation.

The results obtained in this work on sodium-22 agree to within a fraction of one percent with the results of an independent method using electrometer measurements against a known radioactive standard. It is said that the Bureau's new method for the calibration of positron emitters promises to be quite useful, especially since sodium-22 in the form of sodium chloride offers interesting possibilities for use as a biological tracer and as a gamma-ray source in medical therapy.

Production of C^{14} in a Nuclear Reactor

The apparatus in which the first usable quantities of C^{14} were produced is described. Ammonium nitrate solutions were bombarded with slow neutrons in the Oak Ridge nuclear reactor, and the resulting C^{14}, appearing chiefly as carbon monoxide and carbon dioxide, was vented off to be ultimately precipitated as barium carbonate. A total of 440 millicuries, or 88 milligrams, was taken from the extraction trains

By L. D. NORRIS and ARTHUR H. SNELL

Oak Ridge National Laboratory
Oak Ridge, Tennessee

CARBON-14 was discovered several years ago (*1*), and has since held the interest of physicists, chemists, biochemists, and biologists as a tracer isotope of far-reaching possibilities. At the time of its discovery it was known to have a half-life of some thousands of years, a soft beta emission with a maximum energy of approximately 0.15 Mev, and no gamma rays. In addition, it was soon learned that C^{14} could be prepared by slow-neutron capture in nitrogen, $N^{14}(n,p)C^{14}$, with a cross section somewhat larger than $10^{-24}cm^2$ (*2*).

With the development of the nuclear reactor and its ability to abundantly supply thermal neutrons, the existence of this reaction is particularly fortunate. Irradiation of nitrogen in the reactors has made possible the preparation of C^{14} samples thousands of times stronger than those which previously could have been made with long bombardments by the largest cyclotrons. The nitrogen reaction also has another important advantage in that it results in C^{14} which should be isotopically pure, no other carbon being necessarily involved in the process. Consequently, material of high specific activity can be expected—an important consideration when a long half-life is involved.

Early in 1945 at the Oak Ridge National Laboratory a C^{14} "factory" utilizing the $N^{14}(n,p)C^{14}$ reaction was designed and installed in the uranium-graphite reactor. This unit provided for the continuous circulation through the pile of a concentrated solution of ammonium nitrate. Since it was fairly well established that most of the C^{14} would combine with oxygen to form CO or CO_2, a separation tank was placed in the external piping system in order that the product C^{14} plus the radiation decomposition gases could be vented off through an extraction train and the C^{14} removed.

Such a method for producing C^{14} was decided upon because (*a*) a reasonable quantity of nitrogen could be introduced into the pile by virtue of the high water-solubility of ammonium nitrate, (*b*) parasitic neutron capture would not be objectionably large and no competing side reactions would be likely to give conflicting radioactivities requiring special decontamination procedures, (*c*) extensive radiative decomposition of the solution was considered unlikely, (*d*) thermal decomposition of the solution at the contemplated operating temperature would be negligible, (*e*) ammonium nitrate is inexpensive, and

easily obtained pure and in quantity, and (*f*) the method seemed capable of working in a continuous fashion with minimum attention, yielding C^{14} which would be available almost immediately as it was produced. In addition, the necessary apparatus could be rapidly constructed from readily available materials.

C^{14} Production Unit

Figure 1 is a schematic drawing of the production unit; Fig. 2 is an alternate arrangement of the extraction train, which was used in the early stages of operation. This type will be discussed later in more detail. The pump was of the glass centrifugal type, with a nominal rating of 10 gpm. The ammonium nitrate solution was circulated through the irradiation tube in the pile, led into the tall separation tank as indicated, and finally returned to the suction side of the pump to be recycled. The irradiation tube was 30 feet in length, and constructed of 1⅝ in. OD 2S aluminum. It can be described as a twisted U-tube in which the legs of the U lay tightly against each other, the twist providing for complete drainage of solution during periods of inoperation. The separation tank, 6 feet tall and 6 inches in diameter, was also constructed of aluminum, and served (*a*) as a venting-off point for the gaseous products, and (*b*) as a heat exchanger for controlling the solution temperature. To provide protection against any build-up of stray induced activities in the solution, the separation tank was encased in a lead shield one inch thick. The reservoir, a converted stainless steel drum, was used to supply or store solution as needed. The circulating system was constructed only of aluminum, stainless steel, and glass to minimize corrosion. All the connecting piping was ¾ in. ID 2S aluminum. In ordinary operation the circulating system, including the irradiation tube, contained approximately 52 liters, with an active volume in the pile of 17 liters.

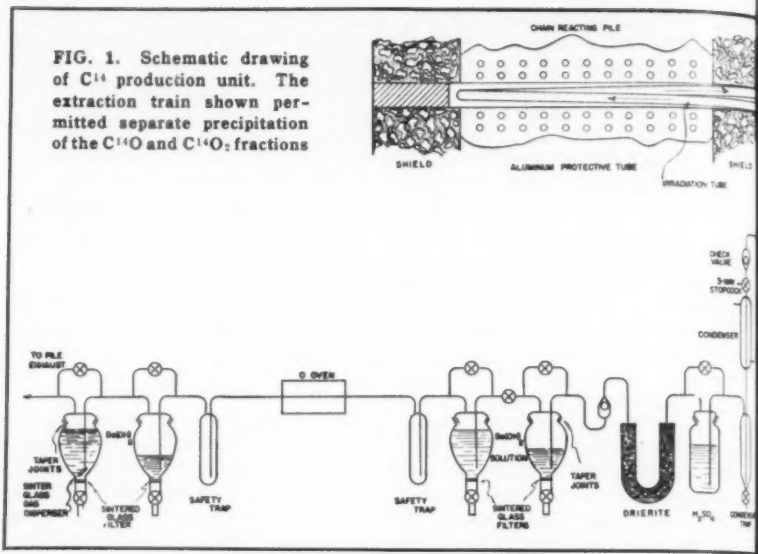
Gases evolved from the solution at the top of the separation tank forced their way through the diagrammed extraction trains. The several different arrangements of extraction train ultimately performed the same basic operations of (*a*) converting to $C^{14}O_2$ that portion of C^{14} present in the gas stream in other forms, and (*b*) precipitating the $C^{14}O_2$ as $BaC^{14}O_3$ by means of saturated barium hydroxide solution, which is a highly efficient reagent for isolating even very small quantities of carbon dioxide.

Circulating System

The ammonium nitrate solution as made up contained 850 gm of chemically pure NH_4NO_3 per liter at room temperature, which corresponded to 98 % of saturation. From this a figure of 5.1 kg is obtained for the amount of nitrogen in the active volume of the irradiation tube. Samples were taken from the circulating system every month and analyzed for total nitrogen. No depletion in nitrogen concentration with time could be observed.

Besides its usefulness in removing the gaseous decomposition products, the rapid (20 l per min) circulation of the ammonium nitrate solution had an added advantage in that it facilitated control of the solution temperature. Since the temperature of the reactor structure in the vicinity of the irradiation tube was known to be somewhat more than 100° C, it was felt that, if for any reason the solution temperature should approach that range, an explosive accident might occur. By adjusting the flow of cold water through the cooling coil in the separation tank, and by ensuring sufficient circulation, the normal operating temperature of the solution was maintained at 25–30° C with no trouble, the temperature being observed continuously by means of a recorder connected to four thermo-

FIG. 1. Schematic drawing of C^{14} production unit. The extraction train shown permitted separate precipitation of the $C^{14}O$ and $C^{14}O_2$ fractions



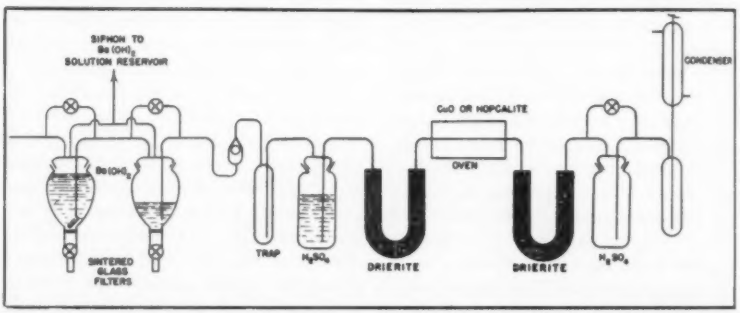
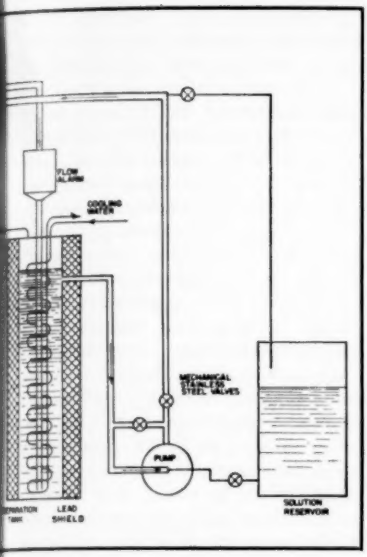


FIG. 2. An extraction train arrangement used in the early stages of operation of the C^{14} production unit. No separation of the $C^{14}O$ and $C^{14}O_2$ fractions was accomplished, all of the C^{14} being first converted to $C^{14}O_2$, and then precipitated

couples placed at equal distances along the irradiation tube. Upon shutting the unit down, the solution temperature was sometimes allowed to rise to 50° C in order to collect as much gas as possible, but prolonged operation at such temperature was avoided because of increased corrosion.

For a warning device a large alarm buzzer was used. This buzzer could be activated by either the thermocouple circuits or the flowmeter (see Fig. 1). If flow of the solution ceased, or if the solution temperature reached 55° C, the buzzer called attention by making violent noises. An additional factor of safety was provided by connecting the reactor trip circuits into the thermocouple network so that a temperature of 85° C would cause a shutdown.



The problem of corrosion was not considered serious at the time of installation of the factory. Experiments had indicated that the effects of saturated ammonium nitrate solution on aluminum and stainless steel were negligible. Unfortunately it was soon discovered that radiation effects in the reactor result in a rapid fall in the *p*H of such a solution. Solution samples, taken at intervals of two weeks during a three month period of almost continual operation, showed a decrease in *p*H from 4.8 (fresh, unbombarded solution) to 2.4. In Fig. 3 the fall in *p*H during this period is plotted against bombardment time in arbitrary units. Because of this increasing acidity, considerably more dissolution of the aluminum pieces of the circulating system occurred than was anticipated, and although such corrosion created no serious mechanical difficulty, the Al^{28} activity induced in the solution materially increased the gamma radiation background around the separation tank pump and piping. Increased shielding and semi-yearly solution changes were resorted to in order to keep the radiation level within permissible bounds.

Gaseous Products

The stream of evolved gas amounted to about 20 cc per minute. Qualitative tests showed that it contained mainly oxygen, nitrogen, hydrogen, and small amounts of nitrogen oxide and ammonia. The suggestion that appreciable amounts of air could be leaking into the system ran counter to the design feature by virtue of which the hydrostatic pressure in the system was nearly everywhere slightly above atmospheric; any inward leak would almost certainly have to be near the inlet side of the circulating pump. Tests on this point will be described under discussion of the appearance of inactive carbon in the product.

In order to take gas samples for counting, a set of mica window gas samplers was constructed, of identical shape and volume, with windows of equal thickness (3.0 mg/cm²). These samplers were evacuated, attached to the gas line at the desired point and filled. For counting the gas samples mica-window GM tubes were employed, the mica-window end of the gas sampler being directed towards that of the counter tube. Decay curves obtained by collecting and counting samples of the gas stream were found to resolve into four components, one of long life

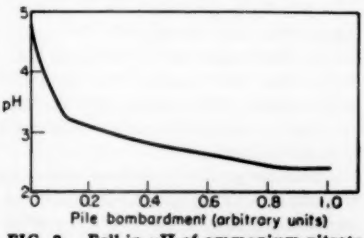


FIG. 3. Fall in *p*H of ammonium nitrate solution plotted against pile bombardment (in arbitrary units)

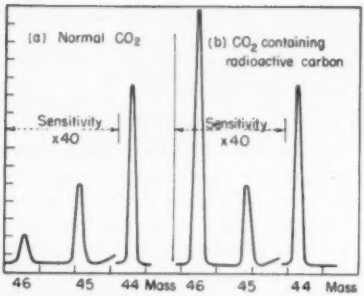


FIG. 4. Recorder tracing of the isotopes in normal carbon dioxide and in carbon dioxide containing C^{14}. The regions about mass 45 and 46 are recorded at 40 times the sensitivity used in recording the mass 44 peaks

which was assumed to be C^{14}, and others with periods of approximately 14.5 hours, 2 hours, and 17.5 minutes. It is likely that the two-hour period is A^{41}, but no attempt was made to identify the activities chemically.

$BaC^{14}O_3$ Product

Removal from extraction train. As can be seen from the diagram of the extraction trains, the bottom sections of the bubblers in which the barium carbonate was precipitated were removable from the train by means of large taper joints. In ordinary operation these bubbler bottoms were changed about once a week.

Upon removing a bubbler bottom from the train, the supernatant saturated barium hydroxide solution was filtered off through the built-in sintered glass filter, and the precipitate washed on the filter with warm water and alcohol. After the alcohol was removed with a gentle stream of air, the precipitate was transferred to a vial and stored in a desiccator.

Chemical purity. Various attempts to generate CO_2 by decomposing barium carbonate taken from the extraction train indicated that the material was not chemically pure. Indeed, the average chemical purity was found to be about 85%, the chief impurities being silica, barium hydroxide, and a difficultly soluble compound of barium which was never identified. It has since been observed that the preparation of barium carbonate of 98% purity or better must be done by precipitation from warm, dilute barium hydroxide solution.

Counting. Thin samples, prepared from the first barium carbonate collected, gave absorption curves which demonstrated the presence of a low-energy beta particle emission. The range of the beta particles, as estimated visually from the absorption curves, was approximately 19 mg/cm² of aluminum. A Feather analysis gave the "Feather" range as being 28 mg/cm², corresponding to an energy maximum of about 0.15 Mev. Since no decay was observed over a period of weeks, it was assumed that the activity present in the barium carbonate was the desired C^{14}. Mass spectrometric analyses of several samples by M. G. Inghram of the Argonne National Laboratory, established beyond doubt that the species responsible for the activity was C^{14}. One of the mass spectrograms obtained by Inghram is reproduced in Fig. 4.

Assay. Routine assay of barium carbonate from the extraction train was accomplished as follows: One portion of barium carbonate was arbitrarily selected as standard material. From this thin samples were prepared and counted in a known geometry in a "low-absorption" counter (*3*). By making the proper scattering and absorption corrections, the specific activity of the standard material was thereby ascertained. All other active barium carbonate was then compared to the standard material by "thick" sample counting, *i.e.*, by comparing similar counting samples made from the unknown and from the standard material, wherein the thickness of barium carbonate in the samples substantially exceeded the range of the

beta particles. For preparing such "thick" samples, aluminum plates were machined with centered wells, the wells being 3/16 in. in diameter and 1/16 in. deep. The carbonate was tightly tamped into these wells until flush with the top of the plate. The surfaces of the plates were then wiped clean, and counts taken with a mica-window GM tube. The thickness of carbonate in the wells approximated 250 mg/cm², which is considerably greater than the beta particle range. When the amount of barium carbonate available for the assay was limited, plates with somewhat smaller wells were sometimes used.

This "thick" sample technique had several definite advantages. Besides being simple and rapid, counting data reproducible to 2% were obtained. Ordinarily, to attain even a minimum degree of precision when counting low-energy beta particles by conventional "thin" sample methods, great care must be taken in preparing samples for counting and in making the corrections necessitated by prominent absorption and scattering effects. Hence "thick" sample counting would seem advisable in those cases where a choice can be made.

Despite the internal consistency of the "thick" sample counts, the probable error in the reported specific activities of our $BaC^{14}O_3$ samples is estimated to be 10%. This resulted from the uncertainty in the calibration of the standard material, and from sampling errors. It should be noted that the chemical impurities present in the barium carbonate product would make isotopic concentrations calculated from specific activity data appear somewhat low. This caution applies to practically all C^{14} samples prepared in this apparatus.

Another matter of interest recently has concerned the possibility that C^{14} might be lost from active barium carbonate through exchange reactions with ordinary carbon (*4*, *5*). In our own case, no statistically significant depletion of activity was observed. Some of the samples were followed for as long as two years, and most of them were exposed for considerable periods to the atmospheric conditions which prevail in a conventional counter room.

Operating Data

The operation of the C^{14} production unit can be conveniently divided into four periods. These periods, which will be described in chronological order, are distinguished by differences in the operation or construction of the extraction train. In the table on this page, typical production figures are given for each period. Such typical production figures were obtained from those intervals in each period during which the unit was operating in a continuous and trouble-free fashion. Note that isotopic concentrations given in the table are denoted as "nominal," being calculated from the respective specific activities and subject to the caution mentioned above concerning the effect of chemical impurities in the samples upon such calculations. These concentrations were obtained using a value of 350 μc per mg of 100% $BaC^{14}O_3$, this value being based on a half-life for C^{14} of 5,100 years recently reported by L. D. Norris and M. G. Inghram (*3*).

Operating period 1. In the earliest arrangement of the extraction train, the gas stream was passed through a pyrex tube, 0.8 cm ID and 30 cm long, containing Hopcalite (a catalyst for oxidizing CO to CO_2 at room temperature in the presence of oxygen), and then bubbled through saturated barium hydroxide solution. This is shown in Fig. 2.

Since the mica window gas samplers described previously were not available at this time, gas sample counting to determine the efficiency of the train for removing C^{14} was not possible. Having little information at hand about Hopca-

Typical Carbon-14 Production Figures for Various Operating Periods

Operating period	*Extraction train arrangement*	*Total C^{14} collected during reported interval (mc)*	*Average specific activity of C^{14} collected (μc/mg)*	*(Nominal) Average isotopic concentration of C^{14} collected (%)*	*Specific activity of best sample collected during reported interval (μc/mg)*	*(Nominal) Isotopic concentration of best sample (%)*	*Relative yield*
1	Hopcalite oxidation; tube room temp; no separation of $C^{14}O$ and $C^{14}O_2$ fractions	61	8.1	2.3	16.8	4.8	0.29
2	CuO combustion tube; 700° C; no separation of $C^{14}O$ and $C^{14}O_2$ fractions	59	13.3	3.8	16.2	4.6	0.27
3	CuO combustion tube; 900° C; no separation of $C^{14}O$ and $C^{14}O_2$ fractions	65	13.4	3.8	15.1	4.3	0.36
4	CuO combustion tube; 900° C; $C^{14}O$ and $C^{14}O_2$ fractions precipitated separately	(CO) 48	—	—	(1) 111 (2) 78	See Ref. 6	0.20
		(CO_2) 37	7.1	2.0	8.5	2.4	0.16

lite, it was soon decided to replace it with copper oxide.

Operating period 2. In this arrangement, the gas stream was passed through a quartz CuO combustion tube, 0.8 cm ID and 30 cm long, at a temperature of 700°C. It was then again led to barium hydroxide bubblers, as shown in Fig. 2.

With the mica window gas samplers now at hand, it was possible to measure the efficiency of this train by comparing the activity of a sampler filled from the entrance gas stream with the activity of a sampler filled from the exit gas stream. It was found that 15–20% of the C^{14} in the gas entering the train was passing through and appearing in the exit gas.

Operating period 3. To improve the efficiency of the extraction system a combustion tube of 2.5 cm ID was substituted for the previous one, and the furnace temperature was raised to 900° C. The larger diameter combustion tube served to increase the contact time of gas and CuO by a factor of 10.

Measurement of the efficiency of this arrangement of extraction train indicated that only 1.0–1.5% of the C^{14} entering was now being lost with the exit gas. A corresponding increase in yield of C^{14} was also observed, as can be seen in the table.

Operating period 4. Since it was thought that a portion of the C^{14} in the gas stream would be in the form of carbon monoxide, the extraction train was altered so as to permit precipitation of the carbon dioxide component of the gas stream in front of the combustion tube (see Fig. 1). The carbon monoxide fraction, being free to pass on to the combustion tube, could there be converted to carbon dioxide, and precipitated separately. By such an arrangement it was hoped to obtain some C^{14} of high specific activity. The table shows that the barium carbonate result-

ing from the carbon monoxide fraction was considerably more active than any previous material, one sample being as much as 40% C^{14} (*6*, *8*).*

By comparing the amount of C^{14} removed from the carbon dioxide fraction with the amount recovered from the carbon monoxide fraction, figures of 56% and 44% are obtained for the percentage of C^{14} present in the gas stream as carbon monoxide and carbon dioxide, respectively. The percentage as carbon monoxide was considerably larger than expected, since it had been thought that no more than 30% of the C^{14} would be in that form.

Measurement of the efficiency of this extraction train showed that it was somewhat more efficient than the other arrangements, less than 1% of the C^{14} being found in the exit gas stream.

Presence of ordinary carbon in extraction train barium carbonate. By making C^{14} from nitrogen it would appear possible to prepare samples containing only C^{14}. Nevertheless, the table shows that barium carbonate removed from the extraction train during the first three operating periods always yielded isotopic concentrations of 5% C^{14} or less. Although 3% C^{14} material is suitable for nearly all tracer work, it was felt from the beginning that attempts to improve the specific activity of the product should be made. Two possible sources of the unwanted ordinary carbon were considered, the first being carbon contamination in the ammonium nitrate solutions, and the second air leakage into the circulating system.

Since facilities were not available for working with large volumes of solution, little effort was made to remove dissolved CO_2 and carbonate contamination from the ammonium nitrate solutions before introducing them into the circulating unit. As a consequence, large amounts of low-activity barium carbonate were taken from the extraction train immediately after changing the ammonium nitrate solution. However, in about five days the amount collected would fall to less than 100 mg per day, and, thereafter neither a decrease in the amount of carbonate formed per day, nor an increase in its specific activity could be observed. Because of this, and in view of the unexpectedly high rate of gas evolution from the ammonium nitrate solution, it seemed possible that leakage of air into the circulating unit was contributing the ordinary carbon. All welds and couplings were examined, especially those at or near the suction side of the pump. The pump was submerged in water, and later placed in a box through which CO_2-free nitrogen was flushed. Despite these efforts, the specific activity of the barium carbonate showed a singular lack of improvement. Hence, we can propose no satisfactory explanation concerning the presence of inert carbon in our C^{14} samples.

Active Carbon in Irradiated Solution

Since the possibility existed that significant amounts of C^{14} in the form of carbon monoxide and carbon dioxide remained dissolved in the ammonium nitrate solutions, these solutions, having been saved and stored in a capped stainless steel drum, were examined several months after the production unit was dismantled. Aliquots were taken, from which the dissolved gases were collected by acidifying and boiling. After adding a small amount of CO_2 carrier to these gases, they were passed through a copper oxide combustion tube, and finally into bubblers containing saturated barium hydroxide solution. Upon counting the resulting barium carbonate, 0.7 mc of C^{14} was accounted for from the total volume of bombarded ammonium

* The precipitate was hard to detect visually; the activity was contained in an almost invisible deposit on the walls of the collecting vessel, and its harvesting was a matter of manipulative delicacy.

nitrate solutions. We take this as good evidence that less than 1% of the C^{14} formed as a gas remained dissolved in the target solutions.

The work of Yankwich, Rollefson and T. H. Norris (*7*) suggested that some of the C^{14} might be present in the solution in the form of formic acid, methanol, and (less probably) formaldehyde. W. B. Leslie of the Chemistry Division of this laboratory analyzed the ammonium nitrate solutions from our unit for the presence of these three compounds. This work has since been described in another paper (*8*). Using Leslie's results, we find that our bombarded solutions contain approximately 2.8 mc, 0.24 mc, and 0.31 mc of C^{14} as formic acid, methanol, and formaldehyde, respectively. It can be seen that Leslie found the formaldehyde fraction more active than the methanol fraction, which was not the case in the earlier reported work. The C^{14} remaining in the ammonium nitrate solutions as formic acid, methanol, and formaldehyde comprised 0.8% of the total amount collected.

Since extensive scanning of the extraction trains and the ammonium nitrate solutions made it impossible for large amounts of C^{14} to escape notice, it was assumed that the presence of significant quantities of C^{14} in any other chemical forms than those already discussed was quite unlikely. Attempts were made to detect the $C^{14}N$ molecule in the gas stream and in the solutions, with negative results.

The Theoretical Yield

It was of interest to see if the absolute yields of C^{14} from the factory are those to be expected from cross-section and neutron flux data. The N^{14} capture cross section for "thermal" neutrons is 1.7 barns (*9*), which should be corrected for the somewhat higher effective temperature [530° K (*10*)] of the neutrons in the Oak Ridge reactor. The corrected value is 1.1 barns. The neutron flux, averaged over the length of the pipe in the reactor, could be estimated from foil measurements taken in the empty hole by Dr. Haydn Jones and his colleagues. The amount of nitrogen under irradiation was, of course, known from the volume of the pipe and the concentration of the solution. When these factors were put together, the estimated yield turned out to be approximately that obtained in actuality. The comparison is, however, not very accurate, because the presence of the solution can be expected to perturb the neutron flux so that it would depart from the value obtained by Jones.

Summary and Conclusions

The equipment was removed from the reactor primarily because it was wasteful of pile reactivity. Ten times the production could be achieved by loading large amounts of calcium nitrate as canned solid around the periphery of the reactor, with a negligible consumption of reactor inhours. The manpower and facilities had become available for the extra work involved. As secondary considerations, the radiation from the Al^{28} in the external piping was a nuisance, and unsteadiness in reactor operation caused by air bubbles in the solution was occasionally disturbing.

The apparatus manufactured a total of 440 millicuries of C^{14} at a time when only microcurie amounts had previously been available. Some of the material was used for the first mass spectroscopic observations and the first reasonably accurate half-life determinations. The high concentration material (40%) was useful for spin determination (*11*), for beta-spectrum studies (*12*), and for other nuclear physics experimentation (*13*). The tracer experiments for which the bulk of the C^{14} was used are too numerous to mention.

* * *

We feel honored to have been associated with the late Dr. Louis Slotin in the early

phases of this work. We are also indebted to E. Meiners, Jr., and F. Schuler, who aided considerably during the initial operation of the unit. A great deal of credit is due Miss Thelma Arnette and Mrs. Ida Coveyou for assistance in the preparation and counting of samples. The majority of the work was done under the auspices of the Manhattan District.

BIBLIOGRAPHY

1. S. Ruben, M. D. Kamen, *Phys. Rev.* **59,** 349 (1941)
2. C. Lapointe, F. Rasetti, *Phys. Rev.* **58,** 554 (1940); W. E. Burcham, M. Goldhaber, *Proc. Cambridge Phil. Soc.* **32,** 632 (1936); T. W. Bonner, W. M. Brubaker, *Phys. Rev.* **49,** 778 (1936)
3. L. D. Norris, M. G. Inghram, *Phys. Rev.* **73,** 350 (1948)
4. W. D. Armstrong, J. Schubert, *Science* **106,** 403 (1947)
5. P. E. Yankwich, AECD 1831
6. As calculated from the specific activities, one gets 32% and 22%, respectively, for these two samples. But F. A. Jenkins, Department of Physics, University of California, has measured band intensities on grating spectrograms prepared from these materials, and has found that the ratio of C^{14} to total carbon is 40% in the one case and 27% in the other (private communication, 1948)
7. P. E. Yankwich, G. K. Rollefson, T. H. Norris, *J. Chem. Phys.* **14,** 131 (1946)
8. W. B. Leslie, MDDC 674
9. H. Lichtenberger, H. Fowler, A. Wattenburg, Manhattan Project Literature, CP-781
10. G. M. Branch, MDDC 747
11. F. A. Jenkins, *Phys. Rev.* **74,** 355 (1948); A. Roberts, *Phys. Rev.* **73,** 1405 (1948)
12. C. S. Cook, L. M. Langer, H. C. Price, *Phys. Rev.* **74,** 548 (1948); L. Feldman, C. S. Wu, *Phys. Rev.* **75,** 1286 A (1949)
13. K. H. Sun, B. Jennings, W. E. Shoupp, A. Allen, *Phys. Rev.* **75,** 1302A (1949)

Domestic Users of Isotopes

IN A SUPPLEMENT to the Sixth Semiannual Report of the Atomic Energy Commission to Congress, Paul C. Aebersold, Chief of the Isotopes Division, Oak Ridge Operations, has submitted many interesting facts and figures concerning the isotopes program which was inaugurated by the AEC on August 2, 1946. He reports, among other information, the domestic users of isotopes, both radioactive and stable. The list which follows is that of users of radioisotopes only. It is divided by state, institution, city, and (in italics) the department(s) of the institution.

RADIOACTIVE ISOTOPES

(July 1, 1946 to June 30, 1949)

Alabama

University of Alabama, University
Biology
Southern Research Institute, Birmingham
Biochemistry
University of Arkansas Medical School, Little Rock
Pediatrics, Radiology, X-ray
Robert L. Dortch, Seed Farm, Scott
Agronomy

California

Birmingham Veterans' Administration Hospital, Van Nuys
Radioisotopes, Physiological Research Laboratories
University of California, Berkeley
Biochemistry, Chemistry, Engineering, Food Technology, Home Economics, Medical Physics (Donner Laboratory), Mineral Technology, Physics, Physiology, Plant Nutrition, Radiation Laboratory, Soils, Veterinary Sciences
University of California Medical School, San Francisco
Medicine, Pharmacology, Radiology
University of California, Los Angeles
Chemistry, Medical Extension
University of California, Riverside
Soils and Plant Nutrition, Plant Physiology
University of California, College of Agriculture, Davis
Chemistry
California Institute of Technology, Pasadena
Biochemistry, Biology, Chemical Engineering, Chemistry, Kellogg Radiation Laboratory, Physics
California Research Corporation, Richmond
Process Research, Chemistry
Cedars of Lebanon Hospital, Los Angeles
Medicine, Radiation Therapy, Research Laboratory
College of Physicians and Surgeons, San Francisco
Biochemistry, Dentistry, Physical Sciences
Corps of Engineers, U. S. Army, Sacramento

Los Angeles Tumor Institute, Los Angeles
Pathology
Navy Medical Research Unit No. 1, Berkeley
Bacteriology
Santa Barbara Cottage Hospital, Santa Barbara
Radiology
Scripps Metabolic Clinic, La Jolla
Shell Development Company, Emeryville
Chemistry, Physics
University of Southern California, Los Angeles
Chemistry, Zoology
University of Southern California, College of Medicine, Los Angeles
Biochemistry, Medicine
Rees-Stealy Clinic, San Diego
Stanford University, Stanford
Chemistry, Bacteriology and Radiology, Hopkins Marine Station
Stanford University Hospital, San Francisco
Radiology
Tracerlab, Inc., Western Division, Berkeley
Chemistry
Union Oil Company of California, Wilmington
Research
U. S. Department of Agriculture, Albany
U. S. Naval Hospital, Oakland
Wadsworth General Hospital, Los Angeles
Radioisotopes Unit
Weather Bureau, Snow Research Laboratory, Soda Springs
Hydrology
X-Ray Engineering Company, San Francisco

Colorado

Colorado A & M Experiment Station, Fort Collins
Agronomy
University of Colorado, Boulder
Isotopes Laboratory
University of Colorado Medical Center, Denver
Biophysics
University of Denver, Denver
Zoology and Chemistry

Connecticut

American Brass Company, Waterbury
Research Laboratory
American Cyanamid Company, Stamford Research Laboratories, Stamford
Physics, Research
Connecticut Agricultural Experiment Station, New Haven
Soils
New Britain General Hospital, New Britain
X-Ray
Yale University, New Haven
Chemistry, Osborn Zoological Laboratory, Physics, Radiology
Yale University Medical School, New Haven
Aeromedical Research Unit, Bacteriology, Pediatrics, Pharmacology, Physiological Chemistry

Delaware

Biochemical Research Foundation, Newark
Cytology, Physics
E. I. du Pont de Nemours and Company, Wilmington
Chemistry, Engineering
University of Delaware, Newark
Chemistry

District of Columbia

Army Medical Center, Washington
Isotope Laboratory
The Catholic University of America, Washington
Chemistry
Georgetown University Medical Center, Washington
Oncology, Pathology
George Washington University School of Medicine, Washington
Pharmacology
Howard University, Washington
Physics, Physiology
Howard University College of Medicine, Washington
Biochemistry, Medicine
National Bureau of Standards, Washington
Radioactivity Section, Spectroscopy Section
National Research Council, Washington
Committee on Growth
Carnegie Institution of Washington, Department of Terrestrial Magnetism, Washington
Biophysics
U. S. Department of Agriculture, Washington
Division of Soils, Fertilizers and Irrigation
U. S. Naval Research Laboratory, Washington
Nucleonics

Florida

University of Florida, Agricultural Experiment Station, Gainesville
Animal Industry
Naval Air Station, Pensacola
Research

Georgia

Emory University, Emory University
Biochemistry, Robert Winship Memorial Clinic, Surgery
University of Georgia School of Medicine, Augusta
Biochemistry

Hawaii, Territory of

Hawaiian Sugar Planters' Association, Experiment Station, Honolulu
Biochemistry and Physiology

Illinois

Abbott Laboratories, North Chicago
Special Research
American Scientific Company, Chicago
Anderson Physiological Laboratories, Champaign
Armour and Company, Chicago
Chemical Research and Development
University of Chicago, Chicago
Chemistry, Institute for Nuclear Studies, Institute for Study of Metals, Rubber Research, Toxicity Laboratory
University of Chicago School of Medicine, Chicago
Anatomy, Biochemistry, Medicine, Pharmacology, Physiology, Radiobiology and Biophysics, Surgery
Chicago Tumor Institute, Chicago
Radiotherapy
Cook County Hospital, Chicago
Radiology
Hines Veterans' Administration Hospital, Hines
Radioisotopes Unit
University of Illinois, Urbana
Animal Science, Chemistry, Electrical Engineering, Physics, Physiology, Preventive Medicine and Public Health
University of Illinois College of Medicine, Chicago
Biological Chemistry, Pathology, Pharmacognosy and Pharmacology
Illinois Institute of Technology, Chicago
Chemistry
Illinois State Water Survey, Champaign
Loyola University, Chicago
Biological Chemistry, Medicine

Northwestern University, Evanston
Chemistry, Physics
Northwestern University Medical School, Evanston
Experimental Medicine
Presbyterian Hospital, Chicago
Biochemistry, Radiology

Indiana

Indiana University, Bloomington
Physics
Miles Laboratories, Inc., Elkhart
University of Notre Dame, Notre Dame
Chemistry
Purdue University, Lafayette
Agronomy, Chemistry, Pharmaceutical Chemistry, Pharmacy, Physics
Sinclair Refining Company, East Chicago
Catalysis Research

Iowa

Iowa State College, Ames
Agricultural Experiment Station, Bacteriology, Chemistry, Institute of Atomic Research, Physics
State University of Iowa, Iowa City
Physics, Physiology, Radiation Research

Kansas

University of Kansas, Lawrence
Chemical Engineering, Chemistry

Kentucky

University of Kentucky, Lexington
Chemistry
University of Louisville, School of Medicine, Louisville
Endocrinology
Medical Department, Fort Knox
Field Research

Louisiana

Louisiana State University School of Medicine, New Orleans
Pharmacology
Ochsner Clinic, New Orleans
Hematology, Medicine
Tulane University, New Orleans
Physiology
Tulane University School of Medicine, New Orleans
Medicine, Physiology, Surgery

Maine

Colby College, Waterville
Chemistry

Maryland

Army Chemical Center, Chemical Corps School, Frederick
Chemistry, Medical Division, Radiological Safety Branch, Research and Development
Johns Hopkins Hospital, Baltimore
Gynecology
Johns Hopkins University, Baltimore
Biochemistry, Biophysics, Chemistry, Medicine, Pediatrics, Physics, Sanitary Engineering, School of Hygiene
Johns Hopkins University Applied Physics Laboratory, Silver Spring
High Altitude Research
University of Maryland, College Park
Chemistry
University of Maryland School of Medicine, Baltimore
Experimental Anatomy, Medicine
National Naval Medical Center, Bethesda
Biochemistry, Pathology, Physiology, Radiology
Sinai Hospital, Baltimore
Medicine, Surgery
U. S. Army Ordnance Department, Aberdeen Proving Grounds
Interior Ballistics Laboratory
U. S. Department of Agriculture, Beltsville
Biochemistry and Physics, Division of Biologically Active Compounds, Horticulture, Soils and Engineering
U. S. Naval Academy, Annapolis
Welding Laboratory
U. S. Public Health Service, National Institutes of Health, Bethesda
Biophysics, Experimental Biology and Medicine, Industrial Hygiene Research, National Cancer Institute, Pathology, Physiology, Tropical Diseases, Venereal Disease Research, Zoology Laboratory
Westinghouse Electric Corporation, Baltimore
X-ray Engineering

Massachusetts

Amherst College, Amherst
Physics
Arthur D. Little, Inc., Cambridge
Atomic Instrument Company, Boston
Beth Israel Hospital, Boston
Medicine
Boston University, Boston
Physics
Cushing Veterans' Administration Hospital, Farmington
Radioisotope Unit
General Electric Company, West Lynn
Thomson Laboratory
Edward S. Gilfillan, Consulting Engineer, Manchester
Harvard University Medical School, Boston
Biological Chemistry, Biophysical Laboratory, Howe Laboratory of Ophthalmology, Industrial Hygiene, Legal Medicine, Medicine, Nutrition, Pharmacology, Physiology, Surgery, Thorndike Memorial Laboratory
Harvard University, Cambridge
Biological Laboratory, Chemistry, Engineering, Physics
Harvard School of Dental Medicine, Boston
Oral Pathology
Marine Biological Laboratory, Woods Hole
Massachusetts General Hospital, Boston
Biochemical Research Laboratory, Medicine, Surgery
Massachusetts Institute of Technology, Cambridge
Biochemistry, Chemistry, Electronics, Mechanical Engineering, Metallurgy, Physics
Massachusetts Memorial Hospital, Boston
Medicine
University of Massachusetts, Amherst
Zoology and Physiology
New England Deaconess Hospital, Boston
Peter Bent Brigham Hospital, Boston
Medicine
Joseph H. Pratt Diagnostic Hospital, Boston
Medicine
Raytheon Manufacturing Company, Newton
Special Tube Section
Tracerlab, Inc., Boston
Tufts College, Boston
Dental School, Physiology

Williams College, Williamstown
Physics
Worcester Foundation for Experimental Biology, Shrewsbury
Physiology

Michigan

Bendix Aviation Corporation, Detroit
Physics
Detroit Edison Company, Detroit
Detroit Institute of Cancer Research, Detroit
Dow Chemical Company, Midland
Spectroscopy Laboratory
Ford Motor Company, Dearborn
Chemical and Metallurgical Research
Harper Hospital, Detroit
Radiology
Industrial Health Conservancy Laboratories, Detroit
University of Michigan, Ann Arbor
Botanical Gardens, Botany, Physics, Roentgenology
University of Michigan Medical School, Ann Arbor
Medicine
Michigan State College, East Lansing
Agricultural Chemistry, Physiology and Pharmacology
Parke, Davis and Company, Detroit
Pharmacology
Western Michigan College of Education, Kalamazoo
Physics

Minnesota

Central Research Laboratories, Inc., Red Wing
Physics
Mayo Foundation, Rochester
Hematology, Medicine, Neurosurgery
University of Minnesota, Minneapolis
Botany, Chemistry, Physics
University of Minnesota Medical School, Minneapolis
Anatomy, Biophysics & Radiology, Physiological Chemistry, Physiology
University of Minnesota Hospital, Minneapolis
Radiation Laboratory, Surgery

Mississippi

Keesler Air Force Base, Keesler
Radiobiological Branch

Missouri

Barnard Free Skin and Cancer Hospital, St. Louis
University of Missouri, Columbia
Botany, Physics
St. Louis University, St. Louis
Anatomy
St. Louis University, School of Medicine, St. Louis
Biochemistry
Washington University, St. Louis
Chemistry, Physics
Washington University School of Medicine, St. Louis
Anatomy, Biochemistry, Mallinckrodt Institute of Radiology, Medicine, Obstetrics and Gynecology, Surgery

Nebraska

University of Nebraska, College of Medicine, Omaha
Physical Medicine, Radiology

New Jersey

Allied Chemical and Dye Corporation, Morristown
Bell Telephone Laboratories, Murray Hill
Chemistry, Physical Research
General Foods Corporation, Central Laboratories, Hoboken
Biophysics Section
Johnson and Johnson Research Foundation, New Brunswick
Merck and Company, Inc., Rahway
Physical and Inorganic Chemical Research
Ortho Research Foundation, Raritan
Biochemistry
Princeton University, Princeton
Physics
Radio Corporation of America
RCA Laboratories Division (Electronic and Tubes), Princeton; RCA Victor Division (Scientific Instruments), Camden
Rockefeller Institute for Medical Research, Princeton
Animal and Plant Pathology, Physiology
Rutgers University, New Brunswick
Chemistry, Soils
Socony Vacuum Oil Company, Inc., Paulsboro
Research and Development
Stevens Institute of Technology, Hoboken
Physics
U. S. Rubber Company, Passaic
Physical Research
U. S. Testing Company, Inc., Hoboken
Radiochemistry

New Mexico

The Lovelace Clinic, Albuquerque
Radiology

New York

Bellevue Hospital, New York City
Psychiatric Division
Brooklyn Cancer Institute, Kings County Hospital, Brooklyn
Radium Therapy
Canisius College, Buffalo
Chemistry
Columbia University, Barnard College, New York City
Zoology
Columbia University, New York City
Biochemistry, Chemistry, Physics, Radiation Laboratory
Columbia University, College of Physicians and Surgeons, New York City
Biochemistry, Neurology, Obstetrics and Gynecology, Radiology
Cornell University, Ithaca
Agronomy, Animal Husbandry, Biophysics, Botany, Chemistry, Laboratory of Nuclear Studies
Cornell University Medical College, New York City
Biochemistry, Pathology, Pediatrics
Distillation Products, Inc., Rochester
Biochemistry
Eastman Kodak Company, Rochester
Photographic Theory, Research Laboratory
General Electric Company, Schenectady
General Engineering Laboratory, High Frequency Division
Harlem Hospital, New York City
Radiation Therapy
Haseltine Electronics Corporation, Long Island
Memorial Hospital, New York City
Medicine, Urology
Montefiore Hospital for Chronic Diseases, New York City
Medical Physics
Mount Sinai Hospital, New York City
Physics, Physiology and Hematology
New York Medical College, New York City
Metropolitan Hospital Research Unit

New York Naval Shipyard, Brooklyn
Optics and Radiology
New York Post-Graduate Medical School and Hospital, New York City
Skin and Cancer Unit
New York State Agriculture Experiment Station, Geneva
Food Science and Technology
New York University, New York City
New York University College of Medicine, New York City
Chemistry, Medicine, Pediatrics, Pharmacology, Physiology
Overly Biochemical Foundation, Inc., New York City
Biochemistry
Peck Memorial Hospital, Brooklyn
Radiology
Polytechnic Institute of Brooklyn, Brooklyn
Chemistry
Public Health Research Institute, New York City
Nutrition and Physiology
Queens College, Flushing
Chemistry
Rensselaer Polytechnic Institute, Troy
Chemistry, Physics
University of Rochester, Rochester
Botany, Chemistry, Physics
University of Rochester School of Medicine and Dentistry, Rochester
Biochemistry, Radiology
Rockefeller Foundation, New York City
International Health Division
Rockefeller Institute for Medical Research, New York City
Biochemistry, Physical Chemistry
Sloan-Kettering Institute for Cancer Research, New York City
Clinical Investigation, Physics
Strong Memorial Hospital, University of Rochester, Rochester
Radiology
The Texas Company, New York City
Research
U. S. Public Health Service, New York City
Tuberculosis Control
U. S. Marine Hospital, Staten Island
Biochemistry, Venereal Disease Research
U. S. Radium Corporation, New York City
Chemistry
U. S. Veterans' Hospital, Bronx
Radiotherapy

North Carolina

Bowman Gray School of Medicine, Winston-Salem
Biochemistry
Duke University, Durham
Physics, Biochemistry
University of North Carolina, Chapel Hill
Pharmacology, Physics
North Carolina State College, Raleigh
Agronomy, Botany
U. S. Public Health Service, Chapel Hill
Syphilis Experiment Laboratory
Wake Forest College, Wake Forest
Chemistry

Ohio

Air Material Command, Wright Field, Dayton
Instrument and Navigation
Antioch College, Yellow Springs
Physics
Battelle Memorial Institute, Columbus
Physics
Case School of Applied Science, Cleveland
Physics
Cleveland Clinic Foundation, Cleveland
Therapeutic Radiology and Research Division
Crile Veterans' Administration Hospital, Cleveland
Radioisotopes Unit
University of Cincinnati, Cincinnati
Chemistry
University of Cincinnati, College of Medicine, Cincinnati
Gastric Laboratory, Medicine
B. F. Goodrich Company
Physical Research, Akron; Physical Research Brecksville
Goodyear Tire and Rubber Company, Akron
Physical Research
Lakeside Hospital, Cleveland
Surgery
Monsanto Chemical Company, Dayton
Physical Chemistry
National Advisory Committee for Aeronautics, Cleveland
Flight Propulsion Research, Instrument Research Division
Ohio Agricultural Experiment Station, Wooster
Agronomy
Ohio State University, Columbus
Agricultural Biochemistry, Chemistry, Medicine, Physics, Surgical Research
Carl F. Prutton & Associates, Inc., Cleveland
Research
Victoreen Instrument Company, Cleveland
Laboratory
Western Reserve University School of Medicine, Cleveland
Biochemistry, Medicine, Microbiology, Pharmacology, Radiology

Oklahoma

Phillips Petroleum Company, Bartlesville
Research

Oregon

University of Oregon, Eugene
Physics
University of Oregon Medical School, Portland
Biochemistry, Experimental Medicine, Thoracic Surgery
Oregon State College, Corvallis
Chemistry and Agricultural Chemistry
Reed College, Portland
Biology, Chemistry

Pennsylvania

Bartol Research Foundation of the Franklin Institute, Swarthmore
Nuclear Physics
Bird Electronic Well Survey, Bradford
Carnegie Institute of Technology, Pittsburgh
Case Research Laboratory, Chemistry, Metals Research, Physics
Frank Hartman Radium Service, Philadelphia
Educational Department
General Aniline and Film Corporation, Easton
Physics
Gulf Research and Development Company, Pittsburgh
Physics
Houdry Process Corporation of Pennsylvania, Marcus Hook
Fundamental Research
Jefferson Medical College, Philadelphia
Biochemistry and Medicine
Jefferson Hospital, Philadelphia
Hematology
Jewish Hospital, Philadelphia
Radiology, X-Ray

Lankenau Hospital, Philadelphia
Metabolic Chemistry
Lehigh University, Bethlehem
Chemistry
Mellon Institute of Industrial Research, Pittsburgh
University of Pennsylvania, Philadelphia
Botany, Johnson Foundation, Physics, Thermodynamic Research Laboratory
University of Pennsylvania School of Medicine, Philadelphia
Clinical Neurology, Pharmacology, Physiological Chemistry, Radiology (Hospital of U. P.), Research Surgery
Pennsylvania State College, State College
Bacteriology
Philadelphia General Hospital, Philadelphia
Metabolic Laboratory, Radiology
University of Pittsburgh, Pittsburgh
Biological Sciences, Physics
University of Pittsburgh School of Medicine, Pittsburgh
Addison H. Gibson Radiation Laboratory
Pittsburgh Plate Glass Company, Creighton
Glass Research Laboratories
Publicker Industries, Inc., Philadelphia
Chemical Research
Temple University Hospital, Philadelphia
Radiology
U. S. Department of Agriculture, Philadelphia
Protein Division
U. S. Radium Corporation, Bloomsburg
Laboratory
Westinghouse Research Laboratories, East Pittsburg
Electronics and Nuclear Physics, Magnetism, Metallurgy and Ceramics

Rhode Island

Brown University, Providence
Physics

South Carolina

Medical College of the State of South Carolina, Charleston
Radiology
Clemson College, Clemson
Physics

Tennessee

Fairchild Engine and Airplane Corporation, NEPA Division, Oak Ridge
Chemistry, Controls of Instrumentation, Experimental Physics Section, Nuclear Science
Knoxville General Hospital, Knoxville
Neurosurgery
Meharry Medical College, Nashville
Biochemistry, Cancer Research, Radiobiology
Oak Ridge National Laboratory, Oak Ridge
Biology
Thayer Veterans' Administration Hospital, Nashville
Radioisotopes Unit
University of Tennessee, Knoxville
Chemistry
University of Tennessee College of Medicine, Memphis
Chemistry, Physiology
University of Tennessee Hospital, Knoxville
Surgery
Vanderbilt University, Nashville
Physics
Vanderbilt University School of Medicine, Nashville
Biochemistry, Medicine, Pathology, Physiology and Surgery

Texas

Air University School of Aviation Medicine, Randolph Field
Biophysics
M. B. Anderson Hospital, University of Texas, Houston
Medicine
Baylor University College of Medicine, Houston
Biochemistry
Baylor University Hospital, Dallas
Biophysics, Pathology
Geophysical Services, Inc., Dallas
Industrial Radiography Laboratory, Beaumont
Maxfield X-Ray and Radium Clinic, Dallas
Rice Institute, Houston
Biology, Physics
Southwestern Medical College, Dallas
Biophysics, Dermatology, Pathology, Pediatrics, Radiology, Surgery
Texas Radiation and Tumor Institute, Dallas
Radiology
Texas Research Foundation, Renner
Industrial Research
University of Texas, Austin
Botany and Bacteriology, Biochemical Institute (Cancer Research), Chemistry
University of Texas, Medical Branch, Galveston
Medical Physics, Physiology
Veterans' Administration Hospital, Dallas
Radioisotope Unit

Utah

American Smelting and Refining Company, Salt Lake City
Agricultural Research
University of Utah, School of Medicine, Salt Lake City
Biochemistry, Internal Medicine, Pharmacology, Physiology

Virginia

Medical College of Virginia, Richmond
Baruch Center of Physical Medicine, Oncology, Surgical Research
University of Virginia, Charlottesville
Pharmacology, Physics

Washington

The Mason Clinic, Seattle
Radiology
University of Washington, Seattle
Chemistry
University of Washington Medical School, Seattle
Anatomy, Medicine
Washington State College, Pullman
Botany, Chemistry, Physics

West Virginia

West Virginia University, Morgantown
Chemistry

Wisconsin

Marquette University Medical School, Milwaukee
Radioisotope
Milwaukee Gas Specialty Company, Milwaukee
Research and Development
University of Wisconsin, Madison
Biochemistry, Chemistry, Institute for Enzyme Research
University of Wisconsin Medical School, Madison
McArdle Memorial Laboratory for Cancer Research, Medicine
Wisconsin General Hospital, Madison
Medicine

Speed of Operation of Geiger-Müller Counters

In discussing the delays caused by electron transit time, discharge development, discharge quenching, and deadtime, the author attempts to show that considerable resolutions are obtainable with Geiger counters which make their application favored over some other highly developed counters

By HENDRIK DEN HARTOG

Laboratory of Physics, Amsterdam University, The Netherlands

IN THE GEIGER DISCHARGE, the migration of the secondary electrons liberated by the radiation, the development of the avalanches, the quenching of the discharge, and the subsequent deionization and recovery of the external circuit involve delays affecting the applicability of Geiger counters in diverse ways.

Inherent Delay Due to Electron Transit Time

When an ionizing particle passes through a Geiger counter, secondary electrons are created along its path. These electrons migrate towards the central wire, and only after the first of them has come quite close to the wire will multiplication start and the discharge proper be initiated. This secondary electron transit time accounts for the delays observed by a number of investigators, such as Rossi and Nereson (*1*), Bittencourt and Goldhaber (*2*), and Ticho (*3*). They show up as fluctuations in the relative time of discharge of two counters used in coincidence counting, and constitute the main source of error in high-resolution coincidence and delayed-coincidence work.

A second, and less troublesome, delay occurs between the time of arrival of the electron near the wire and the moment the discharge has developed sufficiently to allow detection by ordinary means. This second delay, as distinct from the first one, depends critically on overvoltage, and while of the order of 0.1 microsecond at low overvoltages is reduced to about $\frac{1}{10}$ of this figure at an overvoltage of 200 volts.

It would be an easy matter to calculate the first delay if only data were available on the electron mobilities in the mixtures of gases and vapors used in Geiger counters. This, however, is not the case, and therefore direct measurements of counter delays must be resorted to.

Sherwin (*4*, *5*) has measured the delays in a counter traversed, parallel to the axis, by a fine beam of fast beta particles. A direct measure of the radial velocity of the secondary electrons was obtained from the dependence of the time of the discharge on the radial distance of the beta particles from the wire, the time of incidence of each beta particle being found by making it pass quite close along the wire of another counter. For a mixture of 92 mm of argon and 8 mm of amyl acetate (wire diameter 0.12 mm), a transit time of 0.10 microseconds was found for a radial distance of 1 cm. In the high field strength region covered by these measurements, further results seemed to indicate an electron velocity v proportional to $(F/p)^{\frac{1}{2}}$, where F is the field strength and p the total pressure.

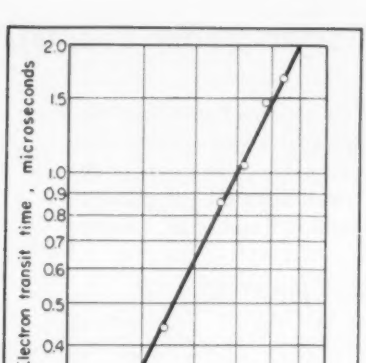


FIG. 1. Dependence of electron transit time on radius traveled in counter containing 90 mm Hg of argon and 10 mm of alcohol (r_a = 0.05 mm) (8)

With F in volts/cm and p in mm of Hg, the measurements appeared to fit the relation

$$v = 4.5 \times 10^6 \left(\frac{F}{p}\right)^{1/2} \text{ cm/sec}$$

At the same time, Hartog, Muller and Verster (6) measured delays in a 68-mm diameter counter containing 90 mm of argon and 10 mm of ethyl alcohol. They used a narrow beam of cosmic rays defined by a counter telescope of 12-mm Geiger counters. Their results, valid for the low field strength region only, shown in Fig. 1, indicate a constant electron mobility k, so that

$$v = kF$$

It can be easily shown that for a pure mobility k the time t during which an electron travels from a distance r to the wire is given by

$$t = r^2 \frac{\ln (r_c/r_a)}{2kV}$$

in accordance with the slope read from Fig. 1. For the mixture mentioned, k = 15,700 cm/sec per volt/cm in the range of F/p from 0.6 to 2 volts/cm per mm of Hg.

Figure 2 contains further data (7, 8) on electron mobilities in counters containing different pressure ratios. This graph is very instructive in that it shows that practically all resistance encountered by the electrons is caused by the alcohol molecules. This phenomenon, although probably of a general nature, is very prominent in argon which has a very low Ramsauer cross section for the electrons slowed down by inelastic collisions with alcohol molecules. This also accounts for the concomitant fact that the figure for k given above is much higher than the mobility in pure argon, which, according to Nielsen (9), is 4,200 for F/p = 1.

The results of Nielsen on electron drift velocities in argon may be roughly described as an $(F/p)^{1/4}$ law, caused by the rapidly increasing Ramsauer cross section with increasing electron velocity. For a constant cross section and very low energy transfer through inelastic collisions, theory predicts an $(F/p)^{1/2}$ law.

As the drift velocity in counter mixtures is largely governed by the organic vapor only, a closer analogy with the behavior in substances presenting a high rate of energy transfer may be expected. In this connection it is highly significant that Nielsen and Bradbury (10) found an exact proportionality of v and F/p in ammonia up to F/p = 6.

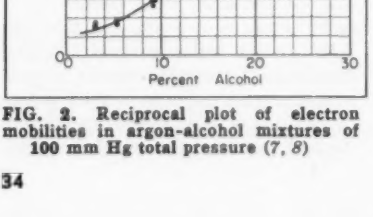


FIG. 2. Reciprocal plot of electron mobilities in argon-alcohol mixtures of 100 mm Hg total pressure (7, 8)

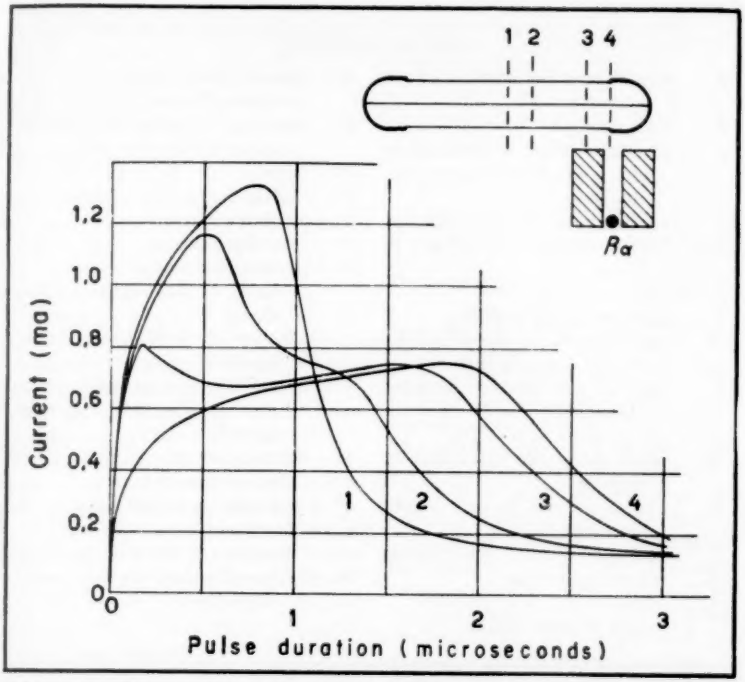


FIG. 3. Counter currents for various points of incidence of gamma radiation. Counter with 45 mm Hg of argon, 45 mm of neon, 10 mm of alcohol vapor. Length of counter 200 mm, r_c = 35 mm, r_a = 0.05 mm. Operating voltage 1,500 volts, appr. 215 volts above starting voltage (*14*)

Be this as it may, the counter data just quoted are poor both in accuracy and extent, and further work is urgently needed to clarify this subject with its many technical and theoretical implications.

The results obtained thus far on self-quenching counters containing argon and an organic quenching agent, such as alcohol or amyl acetate, show that these counters compare favorably as to shortness of electron transit time with the non-selfquenching counters with pure hydrogen or neon fillings, especially when it is remembered that gases such as H_2 and Ne require a much higher pressure for the same density of ionization. For instance, at $F/p = 1$, the electron velocity in a mixture of 90% argon and 10% alcohol vapor is 15.7×10^5 cm/sec, as against 9×10^5 in hydrogen.

Through the work of Townsend and Bailey (*11*, *12*), of Nielsen and Bradbury (*9*, *10*), and of others, enough data are available on mobilities in a number of pure gases to allow reliable calculations to be made on delays in non-selfquenching counters containing such gases. However, here again small admixtures, unintentional or intentional, such as the nitrogen present in commercial argon, or CO_2 added to it, make for a considerable reduction of random

LIST OF SYMBOLS

C	capacitance per unit length of counter	r_a	anode (wire) radius
F	field strength	r_c	cathode-cylinder radius
g	average number of electrons in one cycle of the corona discharge	T	duration of avalanche activity at one point of the wire
I	current in the corona discharge	t	time
I_{min}	"minimum current" giving $\bar{\tau} \simeq$ 1 sec	V	voltage across the counter
$j = \vartheta^+/\vartheta^-$		V_{eff}	effective voltage
k	electron or ion mobility	V_s	starting voltage
M	multiplication in one avalanche	v	electron velocity; velocity of propagation of discharge
n_0	corrected counting rate	x	length of simultaneous avalanche activity
n'	counts per second actually observed	γ	probability for an ion to liberate an electron from the cathode
p	gas pressure, mm of Hg	ϵ	elementary charge
Q_0	space charge per unit length of counter	ϑ^-	electron transit time
Q_1	charge present on unit length of counter wire	ϑ^+	positive ion transit time
R	radius traveled by space charge	τ	deadtime
R_q	quenching resistor	τ_0	deadtime at low counting rate
r	radius traveled by electron; radius of space charge	$\bar{\tau}$	mean life-time of the corona discharge

electron velocity, thus cutting down transit-time delays.

In view of the highly complicated nature of the problem, it is no wonder that a first very sketchy attempt, made by Korff (*13*), at a theoretical calculation of the electron transit time in a selfquenching counter yielded an entirely wrong result.

Development of Discharge Down Counter Wire

Considerable attention has been paid to the mechanism of propagation started in a selfquenching counter once the first avalanche of ionization has been initiated. This mechanism governs the slope of the leading edge of the counter pulse, and, more specifically, a second delay which occurs between the start of the first avalanche and the moment the discharge is developed to such an extent that it can be recorded.

Gemert, Hartog, and Muller (*14*) in 1942 measured the development of the current in a counter containing 45 mm Hg of argon, 45 mm of neon, and 10 mm of alcohol vapor. They used a time base triggered by the rise of the counter pulse itself, and no delay line of any sort, so that the very first parts of their oscillograms are unreliable. Figure 3 shows a family of curves obtained in this way when the counter was irradiated at various points. From these curves it is evident that from the point of irradiation the discharge is propagated in both directions along the wire at a velocity of 10 cm per microsecond until it reaches the ends of the counter. Thus, a pulse started at the center has about half the duration and double the

amplitude of one started at either extremity. The fluctuations in the leading edges of counter pulses caused in this way lead to fluctuations in the times of recording when low-gain amplifiers are used in conjunction with the counters.

Similar oscillograms had already been obtained by Gemert (*15*) in 1940, but the poor accuracy did not at the time allow other than rough conclusions. Further qualitative evidence was reported by Stever (*16*).

A large amount of experimental data have been made available by Alder, Baldinger, Huber, and Metzger (*17–20*). Figure 4 shows some of their data on velocities of propagation v versus counter voltage, for a total pressure of 80 mm Hg with varying alcohol pressure p. (Counter dimensions: cathode 18 mm diam, wire 0.15 mm diam.)

To cite one instance, for a filling of 16 mm of alcohol and 64 mm of argon, with 1,150 volts across the counter and counter dimensions as specified, the velocity was found to be 12×10^6 cm/sec and the rate of current increase at the beginning, 4 ma per microsecond. These data refer to a counter started at the end. Thus, for most pulses, the counter current will rise twice as steeply.

Theories on the mechanism of propagation have been given by the Swiss authors just mentioned, and by Wilkinson (*21*). They are of an altogether different nature, laying stress on opposite aspects of the process, and having in common only that they are highly approximate.

Briefly, the two theories may be outlined as follows:

In the Swiss theory, starting from the first avalanche, the number of photons produced is evaluated. Of these photons, one will have the longest path along the wire and will start a new avalanche there by liberating a photoelectron from an alcohol molecule. (In order to corroborate this theory, a

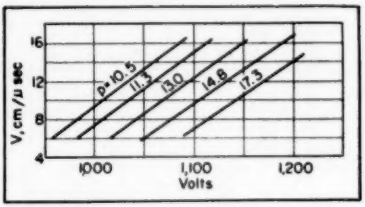


FIG. 4. Velocity of propagation v of discharge down the counter wire (r_c = 9 mm, r_a = 0.075 mm). Total pressure 80 mm Hg, alcohol pressure p as indicated. Measurements of Alder, Baldinger, Huber and Metzger (*17–20*)

separate determination has been made of the absorption of photons in the counter gas.) Before actually starting the new avalanche, the newly created photoelectron has to move to the wire. The small transit time involved introduces a delay before the development of the new avalanche will cause the emission of new photons. The speed of propagation is found as the quotient of the distance covered by the photon reaching farthest along the wire, and the delay caused by the electron transit. For comparison with experiment, this theory, as put forward, needs the determination of three constants not known from other sources, so that the agreement, though probably satisfactory, is not completely convincing.

Quite a different theory has been put forward by Wilkinson and checked very satisfactorily by a number of English investigators.

Starting again with the first avalanche, he studied the development of further avalanches as they are started in the neighborhood of the first one, according to a Gaussian distribution.

From a theory of the development of successive avalanches evolved by the same author, it is possible to determine both the length of wire "burning out"* in this process and the time required for

* "Burn out" refers to the termination of the discharge around the wire. The counter wire is referred to as "burning" when dense avalanche activity takes place in it (*21*).

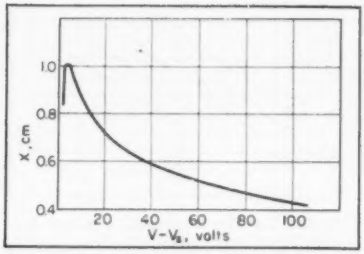


FIG. 5. Theoretical curve of Wilkinson (*21*), showing dependence of length x of counter burning at the same time on overvoltage $V - V_0$ ($r_c = 10$ mm, $r_a = 0.1$ mm). The mean-free-path for photon absorption is assumed to be 1 mm in the counter gas composed of 65 mm Hg of argon and 5 mm of alcohol vapor

the Gaussian distribution to reach a half-width equal to this length.

After this first stage, the adjacent parts of the wire are supposed to burn out next, so that the velocity of propagation is obtained as the quotient of the two quantities enumerated.

It is seen that the Swiss theory neglects the influence of the further development at each point after the first avalanche, and presupposes that no subsequent development can ever lead to a photon-avalanche chain that will overtake the one started first. On the other hand, the English theory, while attempting to evaluate the velocity of propagation of an advanced rather than the initial stage of the discharge, assumes that what happens in the first Gaussian distribution of discharge activity is really representative of what happens later at remoter points of the counter wire.

Even though the argument on the respective merits of these two theories is still going on, it may be interesting to quote two results of the Wilkinson theory, *viz.*, the length x of counter wire burning at a time (Fig. 5) and the time T each point of the wire actually burns (Fig. 6). The data refer to a counter with a wire diameter of 0.2 mm, an alcohol pressure of 5 mm of Hg, and an argon pressure of 65 mm of Hg.

The time T represents the time during which the discharge develops exponentially from the first avalanche to its maximum intensity and is then cut off rather suddenly by the action of the space charge, which temporarily removes the field strength necessary for the process. In view of the exponential increase of avalanche activity, it will be hard to detect a counter discharge much before one period of duration T has elapsed. In fact it is identical in nature with the second delay, independent of the point of incidence of the primary radiation (*5*).

Quenching

No problem of quenching the discharge exists with argon-alcohol and similar counters as the action of the space-charge sheath automatically cuts off the current after an extremely short time, as evidenced by Fig. 7. It is essential for this process that it be possible that the photons emitted by one constituent, in our case the argon atoms, are absorbed by another constituent, such as the alcohol molecules. In counters where such a second constituent is absent, the photons will reach the wall and may liberate new electrons by the photoelectric effect.

Also, to prevent after-discharges from occurring subsequent to the ions falling onto the cathode cylinder, no so-called γ-effect should take place. Here the energy becoming available after the recombination of the positive ions with electrons is transferred to other electrons of the wall so that these are ejected and initiate a new discharge.

As Korff and Present (*22*) have pointed out, in argon-alcohol counters this energy is used for decomposition of the alcohol instead. In this way one of the main advantages of selfquenching counters is obtained only at the expense of a serious drawback.

Quite often, therefore, selfquenching characteristics are dispensed with and fillings such as pure hydrogen, pure argon, argon plus oxygen, or dry air used instead. In these counters, the time required for quenching the discharge may be considerable, and must be taken into account.

The experiments of Ramsey (*23*) and the theoretical discussion of C. G. and D. D. Montgomery (*24*) have shown that argon-oxygen counters are self-quenching in that the discharge is terminated by the space charge, and after-discharges can be avoided by keeping the total capacitance connected to the counter wire down to a very low value and using a high resistor. In these circumstances the counter "overshoots," so that the actual voltage across the counter is still below starting voltage after deionization has been completed. In consequence of the long time constant involved, subsequent recovery is slow, so that these counters can usually be better used with a circuit such as reported on at the end of this article.

In the other counter fillings mentioned above, the counter first breaks into a continuous discharge. When the current is limited by a sufficiently high series resistor, it may sooner or later break off statistically.

For instance, in a counter containing pure argon, new electrons are liberated by the ions returning to the cathode. If the current is limited to an average I, and if the positive-ion transit time is ϑ^+, $\vartheta^+ I/\epsilon$ ions take part in each cycle of the process, where ϵ denotes the elementary charge. If γ is the probability for a positive ion to liberate an electron from the cathode, the number of electrons which take part in each cycle is

$$g = \gamma\vartheta^+ I/\epsilon$$

and if this number is small enough, the probability e^{-g} for no electrons to appear during one cycle becomes appreciable. In fact, it may be shown that

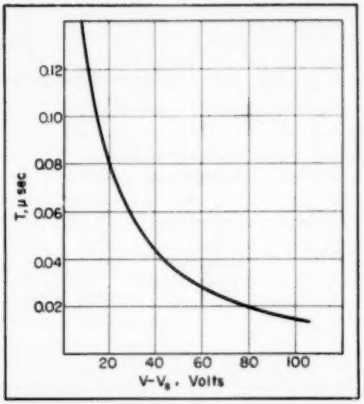


FIG. 6. Wilkinson's theoretical curve for the duration T of avalanche activity at one point of the counter wire. Counter data as for Fig. 5

the mean time after which this will happen is given by

$$\bar{\tau} = (e^g - 1)\vartheta^+/g$$

Geel and Kerkum (*25*), and Schade (*26*) first developed this theory of statistical quenching.

Nawijn (*27–30*) has extended this theory to hydrogen counters, in which the secondary electrons are liberated by the photoelectric effect.

When the formula just derived is applied to this case, with ϑ^- substituted for ϑ^+ since the electron transit time now determines the duration of one cycle of the process, no agreement with experiment is obtained. This is caused

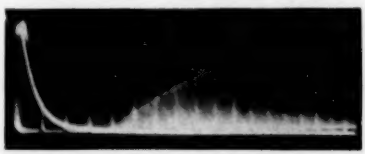


FIG. 7. Counter recovery recorded with time base triggered by counter pulses. Time marks 0.1 milliseconds apart, heavy marks at 0.5, 1, and 1.5 milliseconds. (94 mm of argon, 12 mm of alcohol; r_c = 19 mm, r_a = 0.05 mm) (*8*)

TABLE 1

Orders of Magnitude of Counter Constants

Filling	*Secondary mechanism*	ϑ^+	ϑ^-	j	M	γ	I_{min}, *calculated* (μa)
hydrogen	photoeffect	10^{-5}	10^{-8}	10^3	10^2	0	8
pure argon	γ-effect	10^{-4}	10^{-5}	10^4	10^2	10^{-2}	1.6×10^{-6}
air	photoeffect plus γ-effect	10^{-4}	10^{-5}	10^4	10^3	10^{-3}	1.6

by the fact that, with the photoeffect, the current may within one positive-ion transit time drop in successive stages to zero without the space charge reacting fast enough to interrupt this process. Therefore, when the discharge is limited by the external circuit to a stationary state, so that subsequent to a cycle containing p electrons the average number of electrons will again be p, the probability for the discharge to stop within one cycle ϑ^+ of the reaction of the space charge will be composed of all probability chains starting with q electrons and ending with 0, within the time ϑ^+. Here, the probability for q electrons to follow after a cycle containing p is given by Poisson's formula $(e^{-p}p^q/q!)$.

It must at this stage be stressed that ϑ^+ is of the order of a few microseconds, so that the reaction of the space charge is very fast, the external circuit adjusting the current to a mean value over a prolonged period only.

In this way Nawijn has shown that the mean lifetime of the discharge of a hydrogen counter is given by

$$\bar{\tau} = \vartheta^+ e^{\frac{2}{j}\frac{\vartheta^+ I}{eM}}$$

where $j = \vartheta^+/\vartheta^-$ is of the order of 300, and M is the multiplication occurring in the avalanches, or the ratio of the ion and electron currents measured at the cathode.

For the general case of both γ-effect and photoelectric effect, Nawijn has given the approximated formula

$$\bar{\tau} = \vartheta^+ \exp \frac{\vartheta^+ I}{e} \left\{ \frac{2}{j^2} \left(\frac{1}{M} - \gamma \right) + \gamma \right\}$$

In Table 1, his data are collected for four types of counters. I_{min}, the current giving rise to $\bar{\tau} = 1$ sec, is added for comparison and for later reference. In air the γ-effect predominates in determining I_{min}. For one specific cathode material, $\vartheta^+ I_{min}$ = constant, or, at constant pressure,

$$r_c^2 I_{min} = \text{const. (air)}$$

In hydrogen, on the other hand, $\gamma = 0$, and the photoelectric effect alone governs the process. Here we have at constant pressure

$$r_c I_{min} = \text{const. (hydrogen)}$$

With p in mm of Hg, r_c and r_a in mm, and I_{min} in μa, we have, substituting a number of empirical constants, for air

$$I_{min} = 330 \frac{7.5 + pr_a}{pr_c^2}$$

and for hydrogen

$$I_{min} = 3.6 \frac{(pr_a)^{0.7}}{r_c}$$

With a very high quenching resistor R_q, the discharge is rapidly quenched, but subsequent recovery is slow. Too low a resistor on the other hand will fail to quench the discharge within a reasonable time.

The optimum value recommended by Nawijn is, at an overvoltage $V - V_s$,

$$R_q = \frac{1}{4}\frac{V - V_s}{I_{min}}$$

With hydrogen counters, $V - V_s$ should be of the order of 200 volts to have a sufficiently high efficiency.

For a hydrogen counter with a cathode diameter of 5 mm and a wire of 0.1 mm, of 10 cm length, and with a filling of 300 mm Hg of hydrogen, I_{min} is found to be approximately 10 μa, so that a quenching resistor of 80 megohms is recommended. With this resistor value, and a total wire capacitance of 5 $\mu\mu$f, the recovery time of the counter is 0.17 milliseconds. For the rather complicated calculation the reader is referred to Nawijn's thesis. For larger cathode diameters I_{min} will be smaller, R_q higher, and the recovery accordingly slower.

Instead of a high resistance and a small coupling condenser to the first amplifier tube, a circuit may be used that simulates a high resistance. In this respect, the Neher-Harper (*31*) and Neher-Pickering (*32*) circuits are popular enough to make their inclusion here unnecessary. It may only be stressed that these circuits do nothing but simulate and have no other properties than a high resistance shunted by a small capacitance, and these elements are active both during the quenching and the recovery cycle. The recovery can only be effectively speeded up by circuits having a much more complicated time dependence.

Deadtime

The positive space-charge sheath that cuts off the discharge in a selfquenching counter also keeps this counter insensitive for some time after the discharge has been quenched. During this deadtime the space charge is gradually drawn towards the negative cylinder so that at the same time the negative charge induced on the central electrode is diminished and the field strength around this electrode is gradually restored to normal. Translating this field strength into terms of voltage to be applied to a completely deionized counter in order to establish an equal field strength, and labeling this quantity the *effective voltage*, one may say that after each discharge the effective voltage is slowly restored to normal. Only after this effective voltage has passed the threshold voltage will the counter be capable of registering a new ionizing particle.

Because this insensitive period or deadtime occurs after each discharge, considerable correction must be applied to results obtained at high counting rates. Therefore, a thorough understanding of all factors involved is absolutely essential, and a lengthy discussion seems justified. To prevent undue complications at the outset, the older theories of the deadtime at low counting rates will be treated first, but it must be realized that they can only serve as a background for the more elaborate theories developed lately, and that they cannot in themselves be a basis for satisfactory corrections.

The deadtime phenomenon has already been observed and described very satisfactorily by Trost (*33*) back in 1937, but only on the basis of the quantitative theory of counter deionization given by Montgomery and Montgomery (*24*) was it possible to discuss it quantitatively.

In 1942 two independent papers, one published by Stever (*16*) and one by Gemert, Hartog and Muller (*34*), described very similar oscilloscopic measurements of Geiger-counter recovery. They used a sweep triggered by one counter pulse and showed first a period of insensitivity, followed by one of recovery to normal pulse size. A typical registration is shown in Fig. 7.

It is quite simple to derive an expres-

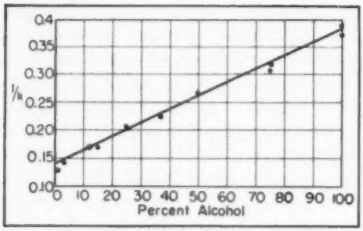


FIG. 8. Reciprocal plot of alcohol-ion mobilities in argon-alcohol mixtures of 100 mm total pressure (8)

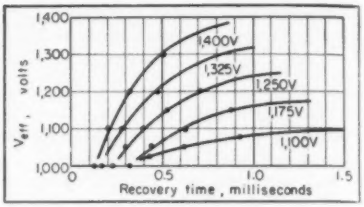


FIG. 9. Recovery of counter described in caption of Fig. 7. Dots are calculated, curves measured. Operating voltages as indicated on curves (8)

sion for the time during which the space charge Q_0 per cm of counter length has drifted in the electric field $F = 2Q_1/r + Q_0/r$ (where Q_1, the charge on 1 cm of counter wire, consists of the charge $+CV$ induced by the cylinder and the charge $-2CQ_0 \ln r_c/r$ induced by the space charge) so far as to restore the effective voltage to V_{eff}. Using a uniform ion mobility k, we have

$$t(R) = \int \frac{dr}{kF} = r_c r_a \ln\left(\frac{r_c}{r_a}\right) \frac{e^{-V/Q_0}}{2kQ_0} \overline{Ei}\left(\frac{V}{Q_0} + \ln\frac{R^2}{r_c r_a}\right)$$

Here $\overline{Ei}(x) = \int_{-\infty}^{x} \frac{e^y dy}{y}$.

Now, by definition, $V_{eff} = V - 2Q_0 \times \ln r_c/R$, so that on eliminating R, we finally have

$$t = r_c r_a \ln\left(\frac{r_c}{r_a}\right) \frac{e^{-V/Q_0}}{2kQ_0} \overline{Ei}\left(\frac{V_{eff}}{Q_0} + \ln\frac{r_c}{r_a}\right)$$

Both the deadtime and the recovery time can be found from this equation by substituting $V_{eff} = V_s$ and $V_{eff} = V$, respectively. This point was questioned by Stever on the ground of variation of k at high field strengths, as observed and explained by Hershey (*35*). However, the velocity of the ion sheath varies approximately as $1/r$, so that the bulk of the delay involved is caused by motion in comparatively weak fields where k may be assumed to be reasonably constant. This conclusion has only recently been borne out by very accurate measurements on counter recovery and deionization currents carried out by Hartog (*8*). Figure 8, summarizing part of his results, gives a reciprocal plot of the mobility of the ethyl alcohol ions observed in a mixture of alcohol and argon, reduced to a total pressure of 100 mm Hg. At the same pressure, the mobility in alcohol is

$$k_{alc} = 2.6 \text{ cm/sec per volt/cm}$$

and in argon is

$$k_A = 7.1 \text{ cm/sec per volt/cm}$$

It must not be overlooked that this latter figure represents the mobility of alcohol ions in argon, no argon ions being present in a selfquenching counter. Figure 9, with full curves measured and dots calculated from the equation just derived, shows how close the agreement between theory and measurements actually is.

For small overvoltages, $\overline{Ei}(x) = e^x/x$, and

$$t = \frac{r_c^2}{2kV_{eff}} \ln\frac{r_c}{r_a} e^{\frac{V_{eff}-V}{Q_0}}$$

As Q_0 depends roughly linearly on $V - V_s$, the deadtime for low overvoltages is constant with constant counter dimensions and gas, and roughly proportional to r_c^2/k. Data

for one specific counter are collected in Fig. 10, and approximative values for other counters may be derived from it, using the k values of Fig. 8.

Corrections for Deadtime Losses

Assuming a low counting rate, we can easily calculate the fractional counting loss from the deadtime τ. If n' counts per second are actually registered, the counter is only operative for the fraction $1 - n'\tau$ of the total measuring time, so that the actual intensity of the radiation is found from

$$n_0 = \frac{n'}{1 - n'\tau}$$

Conversely, the relative counting loss is

$$\frac{n_0 - n'}{n_0} = n'\tau = \frac{\tau}{\tau + 1/n_0}$$

Here, for a very sensitive counting circuit, τ is the deadtime. Otherwise, the time of recovery to the effective voltage necessary for actuating the circuit should be substituted.

Now under actual operating conditions much higher counting rates than $n'_{max} = 1/\tau$ as expected from the above equation have been observed. In this connection the work of Muelhause and Friedman (*36*) should be cited.

As pointed out by Baldinger and Huber (*37*), this is caused by the fact that, at high counting rates, practically all pulses fall well within the recovery time. The ions that are still moving towards the cylinder reduce the field strength around the wire, so that practically all pulses will be much smaller than would be the case at a low counting rate. Now the deadtime after a smaller than normal pulse is smaller than normal also. Accordingly, the mean deadtime is reduced as the counting rate is increased.

Figures 11 and 12 show the very interesting results obtained by Baldinger and Huber by employing a circuit such as used by Stever and by Gemert *et al*, but triggered only by pulses within a definite and adjustable range of sizes. Starting with a given rate of incident radiation n_0, the average pulse size resulting may be read from Fig. 12. For this value of pulse size, Fig. 11 yields the deadtime τ, which is smaller than the deadtime τ_0 for very low counting rates indicated on the abscissa. Once both n_0 and τ are known, the fractional counting loss $\tau/(\tau + 1/n_0)$ may be plotted as indicated in Fig. 12 by the dashed curve.

It follows that even for primary counting rates n_0 as high as 50,000 per sec the counting loss is less than 50%. It should, however, be stressed that it has been assumed that even the smallest

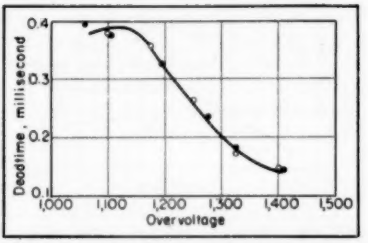


FIG. 10. Deadtimes of argon-alcohol counter at various over-voltages. Dots are measured, curve calculated from theory. Counter data as specified in caption to Fig. 7 (*8*)

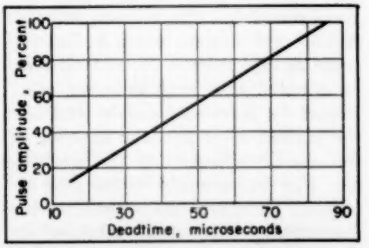


FIG. 11. Dependence of deadtime on pulse size as measured by Baldinger and Huber (*37*). The reduction of pulse size was caused by a high counting rate at a constant operating voltage not specified by the authors. Other counter data: r_c = 9 mm, r_a = 0.05 mm; 83 mm Hg of argon, 5 mm of ethyl alcohol

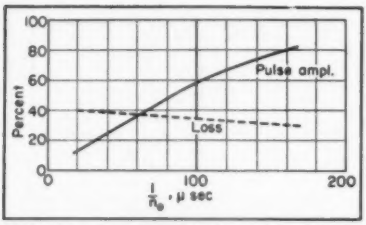


FIG. 12. Average relative pulse amplitude versus corrected counting rate n_0, and counting loss calculated with the help of the average deadtime read from Fig. 11 for each relative pulse amplitude (57)

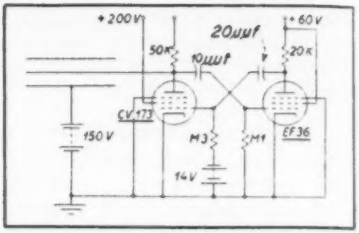


FIG. 13. Circuit for voltage reversal and deadtime reduction developed by Hodson (39). The voltage applied to the anode resistor of tube CV 173 (similar to 807) should exceed the operating voltage of the counter by 150 volts

pulses will be recorded. When a finite sensitivity of the counting circuit is taken into account, the counting-loss curve shows a sharp rise as the average pulse size slips below the threshold value.

Before the experiments of Muelhause and Friedman and the fundamental investigations of Baldinger and Huber, and indeed even after, it had not been fully realized that the deadtime did not really set a low limit on the counting rate. But even so, it must be borne in mind that it will be very difficult in practice to ascertain any high accuracy of correction on the basis of the Baldinger-Huber theory without extensive measurements on the specific type of counter used prior to its being applied to the problem involving high-speed counting. Furthermore, the correction will depend critically on the counting rate unless a circuit sensitivity be adopted that may in every other respect be quite undesirable, and also the plateau slope and the lowering of the counter efficiency at the resulting low V_{eff} be seriously taken into account. Therefore, the attack on the deionization time itself initiated by Simpson (38) and carried on by Hodson (39) remains of current interest.

The long duration of the deionization of a counter results from the fact that in moving towards the cylinder the positive ions travel a long distance in an ever decreasing field. Consequently, the deionization time can be drastically cut down when after each discharge the voltage across the counter is suddenly reversed, so that the wire becomes negative and the positive ions are rapidly drawn to it. In this way Simpson has succeeded in reducing the insensitive time to about 20 microseconds. Figure 13 shows the simplified version of his circuit developed by Hodson. It will be seen that a reversed potential with respect to cathode of 150 volts is applied to the wire subsequent to each counter pulse. Although this voltage must be kept low in order to avoid secondary emission at the wire, a spectacular reduction of from 740 to 30 microseconds has been achieved for a 5-cm diameter counter filled with 15 mm of ether and 115 mm of argon (see Table 2). The success would, however, be much less spectacular for say an 18-mm diameter counter, such as is more common in nuclear work, which has a deadtime of approximately $(18/50)^2 \times 740 = 100$ microseconds, since the reduced deadtime obtainable by the reversal method depends only on the reversed field strength that can safely be accepted in view of secondary emission.

Comparing these results with those obtained by Baldinger and Huber (Figs. 11 and 12) it will be seen that for low and intermediate counting rates the

counting loss (inefficiency) is lower with a reversing circuit, whereas for very high counting rates a sensitive conventional circuit will give a smaller counting loss. It is, however, hard to tell just where either system is superior, as for both, the correction depends as yet on a series of auxiliary measurements. It will be realized that it is not feasible in the circuit of Fig. 13 to find a safe value of the insensitive time from circuit analysis only. In addition, the speed of switchover and recovery of the circuit are such as to cause a marked influence of the counting rate on the insensitive time.

In contrast with the above developments, Hartog and Muller have taken the line that in routine measurements it is best to have a simultaneous determination of the fraction of time during which the counter is sensitive to radiation. This becomes possible when the duration of the insensitive period is determined by a circuit, rather than by the internal mechanism of the counter discharge. It is useful to extend the insensitive period until shortly after the arrival of the positive ions on the cathode cylinder so as to avoid spurious after-discharges initiated by photon emission from the cathode. On the other hand, a very fast circuit reducing the counter voltage below threshold value within a small fraction of a microsecond is also helpful in keeping the total discharge and the amount of alcohol decomposed to a low level, thus extending useful counter life expectancy.

The circuit diagram in Fig. 14 shows a developmental circuit combining the properties enumerated. It can be used not only for selfquenching but for all types of counters.

Connected to the counter wire are the grid of the amplifier tube V_1 that actuates other sections of the circuit, the anode of the quenching tube V_2 that carries the counter wire some 200 volts negative, say 0.2 microseconds after the beginning of the discharge, and the secondary-emission dynode of tube V_4 that restores the working voltage on the counter wire after a suitable delay determined by the timing circuit $V_3 - V_3'$.

TABLE 2

Improvement of Insensitive Time of 5-cm Diameter Counter (15 mm of Ether and 115 mm of Argon) by Means of a Reversing Circuit

	Conventional circuit		*Reversing circuit*	
Counting rate, cps	*Inefficiency, %*	*Insensitive time, microseconds*	*Inefficiency, %*	*Insensitive time, microseconds*
23	1.7	740	0.06	25
124	9.0	730	0.43	35

The operation of the circuit may be described as follows: When the discharge has cut off tube V_1, tube V_2 is made conducting and the voltage on the wire drops so as to make the counter inoperative. Also by means of a d-c connection, the multivibrator $V_3 - V_3'$, which is normally cut off, becomes capable of oscillation. At first V_3 will become the conducting tube so that its anode drops nearly 350 volts, thus reducing the voltage across the 100-megohm resistor, connected to the counter wire, to zero. At the same time, the capacitor connecting the anode of tube V_3' to the cathode of tube V_4 is charged. After completion of the relaxation cycle, this capacitor is discharged through tube V_4, and by the action of secondary emission the wire voltage is rapidly restored to normal.

By virtue of the d-c coupling both of the counter to V_1 and of V_1 to V_3, the circuit will under all conceivable circumstances come to the rescue of the counter. The resistor R in the timing circuit determines the delay after which

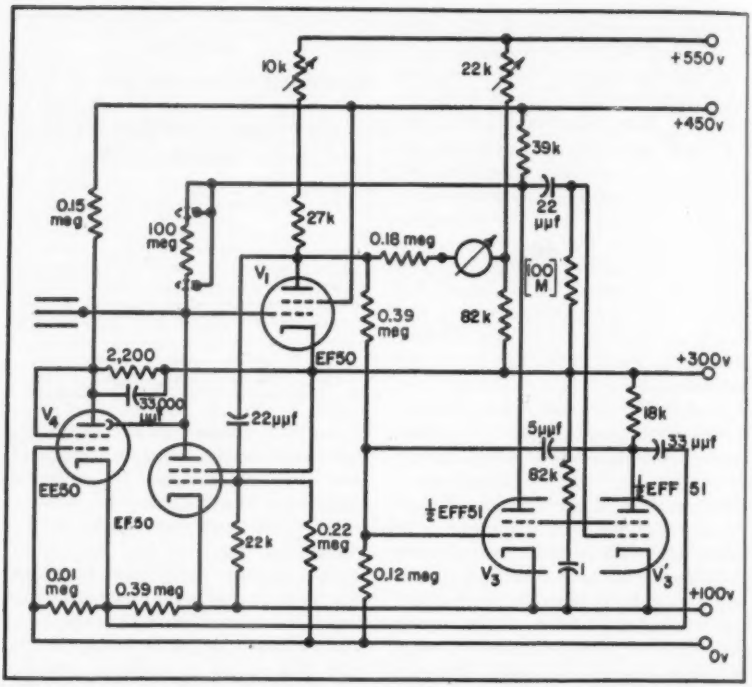


FIG. 14. Circuit for automatic indication of deadtime correction developed by Hartog and Muller (8). The correction to be applied is read from the milliammeter. The resistor referred to as R in the text is indicated as [100 M]

the voltage is re-established and will, according to the diameter of the counter used, be chosen between 10 and 100 megohms.

The two variable resistors should be adjusted so that the milliammeter carries 1 ma with V_1 conducting and 0 ma with V_1 in the non-conducting state. Then this meter will indicate the fraction of time during which the system is sensitive to radiation, and by dividing the number of counts recorded by this fraction, the actual intensity is directly obtained.

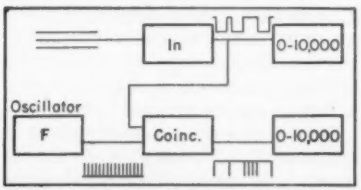


FIG. 15. Block diagram of improved system of automatic deadtime correction. The corrected counting rate is found from the readings of the two scaling circuits (8)

It will be noted that for its correct operation this system depends only on the adjustment of two variable resistors, which can be easily checked and corrected if necessary. No other constants of the circuit enter in the correction provided they lie within reasonable limits, nor do the specific properties of the counter used, which also operates at constant efficiency and active surface.

To cite one instance, a rate of 20,000 per second was observed with a 12-mm diameter counter, R being chosen at 10 megohms. The counter was sensitive for only 15% of the time, so that only 3,000 counts per second were actually observed. The only disadvantage of this system is that for considerable corrections the correction meter must be observed all the time and an average reading taken. This cannot successfully be done by unskilled operators.

In an improved system, shown in the block diagram (Fig. 15), one scaler counts the number of Geiger-counter pulses observed with the circuit just described, while a second one counts the number of coincidences of pulses derived from a crystal oscillator with gates indicating sensitive periods of the counter. The actual intensity is found by multiplying the frequency of the oscillator by the ratio of the two scaler readings.

Only quite recently a circuit has been published by Cooke-Yarborough, Florida and Davey (*40*), useful only with selfquenching Geiger counters. This circuit introduces an artificial insensitive time that is determined by a number of circuit constants. This insensitive time must be accurately known in correcting for deadtime losses. For the very skillfully designed circuit the reader is referred to the original paper, but it is thought that it has only limited applicability compared with the earlier work reported.

BIBLIOGRAPHY

1. B. Rossi, N. Nereson, *Phys. Rev.* **62,** 417 (1942)
2. P. T. Bittencourt, M. Goldhaber, *Phys. Rev.* **70,** 780 (1946)
3. H. K. Ticho, *Rev. Sci. Instr.* **18,** 271 (1947)
4. C. W. Sherwin, *Phys. Rev.* **71A,** 749 (1947)
5. C. W. Sherwin, *Rev. Sci. Instr.* **19,** 111 (1948)
6. H. den Hartog, F. A. Muller, N. F. Verster, *Physica* **13,** 251 (1947)
7. H. den Hartog, F. A. Muller, C. S. W. v. Rooden, *Physica* (in press)
8. H. den Hartog, "Counters with Argon and Alcohol," Thesis (Amsterdam, 1948, in Dutch)
9. R. A. Nielsen, *Phys. Rev.* **50,** 950 (1936)
10. R. A. Nielsen, N. E. Bradbury, *Phys. Rev.* **51,** 69 (1937)
11. J. S. Townsend, V. E. Bailey, *Phil. Mag.* **43,** 593 (1922)
12. J. S. Townsend, V. E. Bailey, *Phil. Mag.* **44,** 1033 (1922)
13. S. A. Korff, *Phys. Rev.* **72,** 477 (1947)
14. A. G. M. van Gemert, H. den Hartog, F. A. Muller, *Physica* **9,** 556 (1942)
15. A. G. M. van Gemert, "Intensity Measurements of Cosmic Radiation in Water and in the Earth's Crust," Thesis (Amsterdam, 1940, in Dutch)
16. H. G. Stever, *Phys. Rev.* **61,** 38 (1942)
17. P. Huber, F. Alder, *Helv. Phys. Acta* **18,** 232 (1945)
18. P. Huber, F. Alder, E. Baldinger, *Helv. Phys. Acta* **19,** 204 (1946)
19. P. Huber, F. Alder, E. Baldinger, F. Metzger, *Helv. Phys. Acta* **19,** 207 (1946)
20. F. Alder, E. Baldinger, P. Huber, F. Metzger, *Helv. Phys. Acta* **20,** 73 (1947)
21. D. H. Wilkinson, *Phys. Rev.* **74,** 1417 (1948)
22. S. A. Korff, R. D. Present, *Phys. Rev.* **65,** 274 (1944)
23. W. E. Ramsey, *Phys. Rev.* **75,** 1022 (1940)
24. C. G. Montgomery, D. D. Montgomery, *Phys. Rev.* **57,** 1030 (1940)
25. Chr. van Geel, J. Kerkum, *Physica* **5,** 609 (1938)
26. R. Schade, *Z. tech. Physik* **104,** 500 (1937)
27. A. Nawijn, "The Discharge Mechanism of the Geiger-Müller Counter," Thesis (Delft, 1943, in Dutch)
28. A. Nawijn, *Physica* **9,** 481 (1942)
29. A. Nawijn, J. de Jong, *Physica* **10,** 513 (1943)
30. A. Nawijn, D. Mulder, *Physica* **10,** 531 (1943)
31. N. V. Neher, W. W. Harper, *Phys. Rev.* **49,** 940 (1936)
32. N. V. Neher, W. H. Pickering, *Phys. Rev.* **53,** 316 (1938)
33. A. Trost, *Z. Physik* **105,** 399 (1937)
34. A. G. M. van Gemert, H. den Hartog, F. A. Muller, *Physica* **9,** 658 (1942)
35. A. V. Hershey, *Phys. Rev.* **56,** 908 (1939)
36. C. O. Muelhause, H. Friedman, *Rev. Sci. Instr.* **17,** 506 (1946)
37. E. Baldinger, P. Huber, *Helv. Phys. Acta* **20,** 470 (1947)
38. J. A. Simpson, *Phys. Rev.* **66,** 39 (1944)
39. A. L. Hodson, *J. Sci. Instruments* **25,** 11 (1948)
40. E. H. Cooke-Yarborough, C. D. Florida, C. N. Davey, *J. Sci. Instruments* **26,** 124 (1949)

Fast Pulse Amplifiers for Nuclear Research

By W. C. ELMORE
Swarthmore College, Swarthmore, Pennsylvania

PULSE AMPLIFIERS find considerable application in nuclear research for amplifying low-level signals from various electronic detectors of radiation. Amplifiers of this sort are usually designed to have a number of special properties required by the nature of the signal being amplified, and by the desired form of output signal. Often the amplifier is used as a ballistic device, that is, an output pulse of short duration is generated in response to each step-like input signal. In this way a pile-up of successive signals is avoided, and each ionizing particle that enters the electronic detector produces a distinct output pulse for recording. A linear relation is usually desired between the amplitudes of the input and output signals.

With the adoption of electron collection in ionization chambers, and in detectors employing gas amplification, it has become important to design amplifiers having a speed of response approaching the limit that can be achieved with conventional tubes and circuits. The recent development of the scintillation counter employing an organic phosphor and a photomultiplier tube has given an added impetus to the design of very fast amplifiers.

In the present article a discussion will be made of some of the limitations affecting the speed of response of non-feedback amplifiers, and of the design of amplifiers whose speed of response approaches the theoretical limit.

Amplifier Rise Time

In analyzing the circuit of an amplifier for speed of response, it is customary to assume that a step-function voltage signal is applied to the input grid, and that the low-frequency response characteristic of the amplifier is perfect. In such a case the output signal $e(t)$ rises from zero to a final steady value, either with a monotonic increase, as indicated in Fig. 1*a*, or with a temporary overshoot of the final value, as indicated in Fig. 1*b*. In actual pulse amplifiers the low-frequency characteristic is chosen to reduce the output signal to zero soon after the steep rise is nearly completed. This behavior can be disregarded in considerations of the speed of rise.

In the following treatment we shall assume that each stage of the amplifier has the monotonic type of response. The discussion is limited to this case because of the difficulty in giving a general treatment to stages whose response possesses some degree of overshoot. The results of the analysis, however, should have approximate validity for amplifiers in which a small percentage overshoot exists. Since most pulse amplifiers used with electronic detectors are designed to have negligible overshoot, the limitation of the treatment to this case does not detract seriously from its usefulness.

An alternative method of studying the speed of amplifier response is to assume that an impulse of voltage is applied to the input grid. The output signal then consists of the time derivative $e'(t)$ of the curves shown in Fig. 1. An impulsive signal of infinitesimal duration thus emerges as a pulse of finite duration. The rise time T of an amplifier having a monotonic response to a step function is most conveniently defined as $\sqrt{2\pi}$ times the standard deviation of the pulse $e'(t)$ (*1*). This

definition of rise time gives numerical values that differ but little from values based on customary laboratory definitions, for instance, the time for $e(t)$ to rise from 10 to 90% of its final value. It has the advantage that a rise time can be computed very quickly from the Laplace transform system function of the amplifier. Details of this calculation can be found elsewhere (*1*, *2*).

An important consequence of defining rise time as proportional to the standard deviation of the pulse $e'(t)$ is the following theorem (*1*):

THEOREM I: If T_i is the rise time of the ith stage of an n-stage amplifier, then the over-all rise time is given by

$$T = \sqrt{\sum_{1}^{n} T_i^2}$$

From Theorem I, and from the fact that the gain of an amplifier is proportional to the product of the plate-load resistances, it is not difficult to prove a second important theorem:

THEOREM II: The rise time of an amplifier of specified gain is a minimum when the plate-load resistances are so chosen that each stage has the same rise time. It is here assumed that the transconductance and parasitic (or stray) capacitance of each stage are definite, fixed quantities.

The two theorems quoted permit us to tackle the problem of designing a fast multi-stage amplifier of specified gain and rise by designing the individual stages one by one. Hence let us first consider a resistance-coupled amplifier stage based on a pentode having transconductance g_m. Such a stage has at high frequencies the simplified equivalent circuit shown in Fig. 2, where R is the plate-load resistance and C the total parasitic capacitance shunting the resistance. From the definition of rise time it is found that the stage has the rise time

$$T = \sqrt{2\pi}\, RC \qquad (1)$$

Inasmuch as the voltage gain is

$$G = g_m R \qquad (2)$$

the gain-rise-time quotient for the stage is

$$\frac{G}{T} = \frac{g_m}{\sqrt{2\pi}\, C} \qquad (3)$$

The resistance-coupled stage can be modified in several ways to increase its speed of response. This is accomplished by incorporating one or more so-called compensating elements (involving the use of small inductances) in the coupling network between the plate of one tube and the grid of the next. In all cases in which the transient response is monotonic the rise time can be written

$$T = \sqrt{2\pi}\, RC/S \qquad (4)$$

so that the gain-rise-time quotient becomes

$$\frac{G}{T} = S\,\frac{g_m}{\sqrt{2\pi}\, C} \qquad (5)$$

The quantity S may be termed the rise-

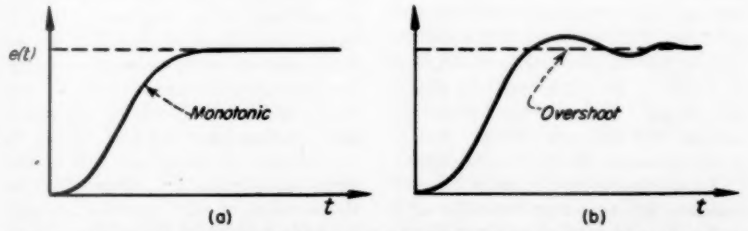


FIG. 1. Curves showing transient response of amplifier to a step function (*a*) when the response is monotonic, and (*b*) when overshoot exists

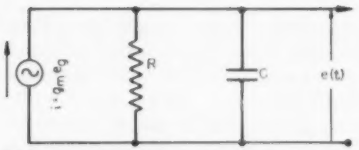


FIG. 2. Simplified equivalent circuit at high frequencies for a resistance-coupled amplifier stage

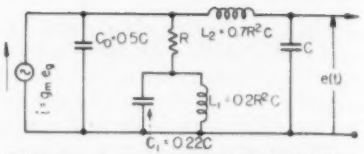


FIG. 3. A useful four-terminal interstage for a 1-to-2 capacitance ratio

time figure-of-merit for the interstage network. Numerical values of S for several interstages are given in the next section. The rise time for unity gain

$$\tau = \frac{T}{G} = \frac{\sqrt{2\pi}\,C}{Sg_m} \qquad (6)$$

is a useful parameter in developing the theory of the transient response of multi-stage amplifiers.

Interstage Network

The simplest amplifier stage employs a plate-load resistance R shunted by the parasitic capacitance C consisting of the sum of the output capacitance, the wiring capacitance and the input capacitance of the following stage. For this case a comparison of Eqs. 1 and 4 shows that $S = 1$, *i.e.*, the resistance-coupled stage serves as a standard for evaluating the performance of stages that are compensated to improve their speed of response. If an inductance

$$L = \alpha R^2 C \qquad (7)$$

is connected in series with the plate-load resistance, the well-known shunt-compensated two-terminal interstage is formed. The shortest rise time with no transient overshoot is obtained with $\alpha = \frac{1}{4}$. For this value of the inductance it may be shown that $S = \sqrt{1\frac{9}{16}} = 1.512$ (*1*, *2*). The inductor should be placed between the plate-load resistor and the power-supply bus to avoid increasing the circuit capacitance.

A somewhat greater value of S can be achieved by increasing the value of α in Eq. 7 to $\frac{5}{17}$ and shunting it by the capacitance $C_1 = \frac{1}{6}C$. The value of S in this case is 1.769. This, and other two-terminal interstage networks incorporating additional inductances and capacitances, and possessing no transient overshoot are described in reference *1*. The maximum value of S that can be obtained in this manner is $3/\sqrt{2}$ $(= 2.12)$ as the number of compensating elements is increased indefinitely.

If more than one inductance is to be used in a single interstage, a four-terminal network in which the output and input capacitances are treated as separate elements gives better performance than any of the two-terminal networks. The writer does not know of any networks of this type that are completely free from a small amount of transient overshoot. There exist two such networks, however, for which the amount of overshoot is so small (a few percent or less) that they are extremely useful. The present theory may be applied to them without serious error. Equivalent circuits for the two networks are given in Figs. 3 and 4 (*3*). Each network requires a definite ratio between output and input capacitances, as indicated in the diagrams. One or the other of these ratios can often be obtained in practice, without increasing the total parasitic capacitance, by the simple expedient of locating the plate-grid coupling capacitor (not shown in the figures) on the proper side of the series inductance L_2. Depending on the location of this capacitor, a considerable portion of the wiring capacitance is placed in parallel with either

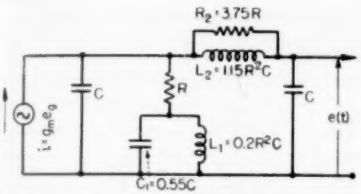


FIG. 4. A useful four-terminal interstage for a 1-to-1 capacitance ratio

the input or the output capacitance of the network. The approximate value of S for the circuit of Fig. 3 is 2.5, and for the circuit of Fig. 4, 2.2. These values, which may be slightly high, have been estimated from a plot of the transient response curves for the networks, as given in reference *3*.

Multi-stage Amplifiers

Let us suppose that a particular type of coupling network, and, therefore, the value S_i, has been chosen for each of the $i = 1, 2, \ldots, n$ stages, and that the values of the parasitic capacitance C_i and transconductance g_{mi} for each stage have been assigned. For the amplifier to have a minimum rise time for a given gain, Theorem II requires that each plate-load resistance R_i be chosen to make the rise time of all stages the same. According to Eq. 4 the plate-load resistances must therefore satisfy the equation

$$\frac{T_0}{\sqrt{2\pi}} = \frac{R_1C_1}{S_1} = \frac{R_2C_2}{S_2} = \ldots = \frac{R_nC_n}{S_n} \quad (8)$$

where T_0 is the rise time of a single stage. The gain of the n-stage amplifier is

$$G = \prod_1^n G_i = \prod_1^n g_{mi}R_i \quad (9)$$

where $G_i = R_ig_{mi}$ is the gain of the ith stage.

Equations 8 and 9 suffice to determine the values of all plate-load resistors. A convenient method of carrying out this calculation is as follows: The gain of the ith stage is

$$G_i = R_ig_{mi} = \frac{S_ig_{mi}T_0}{\sqrt{2\pi}\,C_i} = \frac{T_0}{\tau_i} \quad (10)$$

where τ_i is the rise time for unity gain of this stage (Eq. 6). The value of T_0 is found from

$$T_0^n = G\prod_1^n \tau_i \quad (11)$$

which follows from Eqs. 9 and 10. We see that if a value of T_0 is computed from Eq. 11 for a desired gain G and for given values of τ_i, the gain of each stage, and the requisite plate-load resistance can be computed from Eq. 10. According to Theorem I and Eq. 11, the rise time of the n-stage amplifier is

$$T = \sqrt{n}\,T_0 = \left(\prod_1^n \tau_i\right)^{1/n}\sqrt{n}\,G^{1/n} \quad (12)$$

A simplification in the analysis results for the case in which the values of g_{mi}, C_i and S_i are such that all τ_i are equal to the same value τ_0. The gain of each stage is then

$$G_0 = G^{1/n} = g_{mi}R_i = \frac{T_0}{\tau_0} \quad (13)$$

and Eq. 12 for the rise time of the n-stage amplifier becomes

$$T = \sqrt{n}\,T_0 = \tau_0\sqrt{n}\,G^{1/n} \quad (14)$$

For purposes of design it is useful to consider the function

$$f(n) = \sqrt{n}\,G^{1/n} \quad (15)$$

that occurs in Eqs. 12 and 14. It expresses the ratio of the amplifier rise time to the geometric mean of the rise times of individual stages when they possess unity gain. The function $f(n)$ has a minimum value when $n = 2\log_e G$, that is, when

$$G_0 = e^{1/2} = 1.65 \ldots \quad (16)$$

The function is presented graphically in Fig. 5 for values of G in the range from 10 to 10^6.

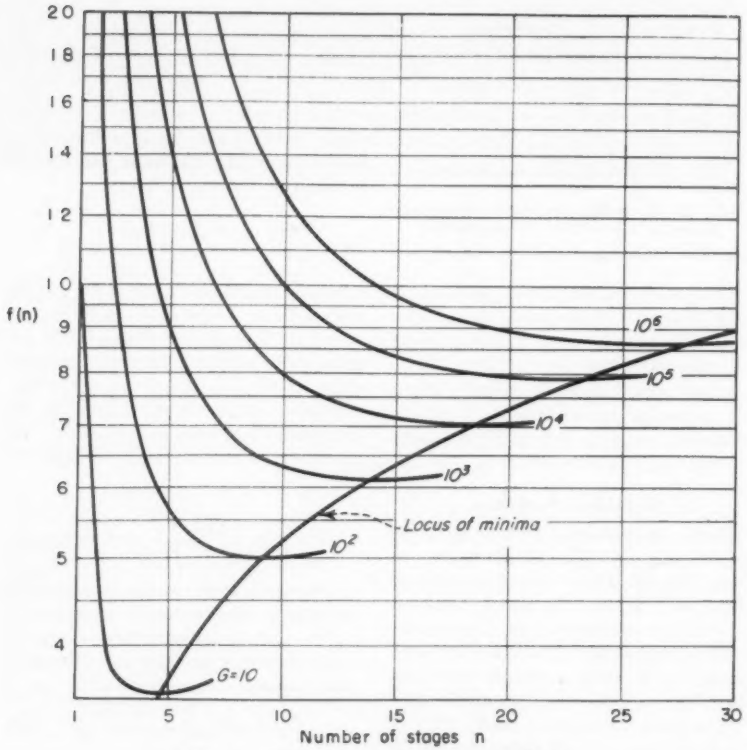


FIG. 5. Plot of the function $f(n) = \sqrt{n}\, G^{1/n}$

The family of curves in Fig. 5 has a number of uses. From them one can readily judge how the rise time is altered if the number of stages is increased and the plate-load resistances of all stages are reduced proportionately in order to maintain the same over-all gain. The curves are also useful in estimating how the rise time is affected if the number of stages is kept fixed and the over-all gain is increased (or decreased) by increasing (or decreasing) all plate-load resistances a proportionate amount.

Perhaps the most important application of the curves arises in the design of an amplifier of given gain having the shortest possible rise time. Although Eq. 16 indicates that the gain of each stage should be made 1.65, it is evident from the curves that the function $f(n)$ has a very broad minimum. The curves are very useful, therefore, in helping to decide how many stages can be economically incorporated in the amplifier. In most instances a sacrifice in rise time of perhaps 10% is not a serious penalty to pay in order to reduce the number of stages required. For example, if the amplifier is to have a gain of 1,000, 13 or 14 stages are required to achieve the minimum rise

Some Tubes Useful In Pulse Amplifier Design

	I_p (ma)	g_m (mhos)	C_i ($\mu\mu f$)	C_o ($\mu\mu f$)	τ (μsec)	$I_p/(C_o + 10)$ ($ma/\mu\mu f$)
6SH7	10.8	.0049	8.5	7.0	.0105	.64
6AU6	10.8	.0052	5.5	5.0	.0075	.72
12AW6	7.2	.0051	6.5	1.5	.0064	.69
6AK5	7.7	.0051	4.0	2.8	.0058	.60
6AG5	7.2	.0051	6.5	1.8	.0065	.61
6AC7	10	.009	11	5	.0059	.67
6AG7	30	.011	13	7.5	.0058	1.71
6AS5	35	.0056	12	6.2	.0104	2.16
6AN5	35	.008	9.0	4.8	.0059	2.36
807	72	.006	11	7.0	.0096	4.24
829B	60	.0085	14.5	7.0	.0078	3.53

time. A rise time 10% greater requires only seven stages, each having a gain of about 2.7. The individual plate-load resistances are then about 60% greater, permitting a 60% increase in signal level with the same amount of non-linear distortion.

Computation of τ

The function $f(n)$ defined by Eq. 15 and presented graphically in Fig. 5 is the ratio of the amplifier rise time T to the geometric mean of the rise times for unity gain τ_i, which characterize the individual stages. The rise time of the amplifier can be quickly estimated from Fig. 5 for various combinations of n and G provided one has determined the values of τ_i from Eq. 6.

To facilitate the computation required by Eq. 6 the nomograph given in Fig. 6 has been prepared. The value of S, the rise-time figure-of-merit for the interstage coupling, has been placed on the first line of the nomograph. A line is drawn from the value selected for S, through the value of g_m, the tube transconductance, and extended to the pivot line at the right of the diagram. From the point of intersection on this line, a second line is drawn through the value of C, the interstage parasitic capacitance, and extended until it meets the line designated by τ. The intersection on the latter line gives the value of the rise time for unity gain in microseconds.

Choice of Tubes

In designing a practical pulse amplifier particular care must be exercised in selecting the type of tube most suitable for each stage of the amplifier. The greatest difficulty in design often occurs at the output of the amplifier. One usually desires output signals of considerable amplitude, either for deflecting the spot of a cathode-ray tube, or for the purpose of sorting and recording pulses according to their amplitudes. It is sometimes found necessary to depart to a certain extent from the ideal condition of equal rise time for all stages, taking a loss in the output stage in order to obtain a sufficiently large range of linear operation for this stage.

If the amplifier is to have high gain, then special attention must be paid to the input stage in order to achieve as good a signal-to-noise ratio as possible. Experience indicates that a type 6AK5 tube makes a particularly good input stage when shot noise is a limiting factor. It would take us too far afield, however, to discuss problems of signal-to-noise ratio. Hence it will be assumed that noise considerations are not

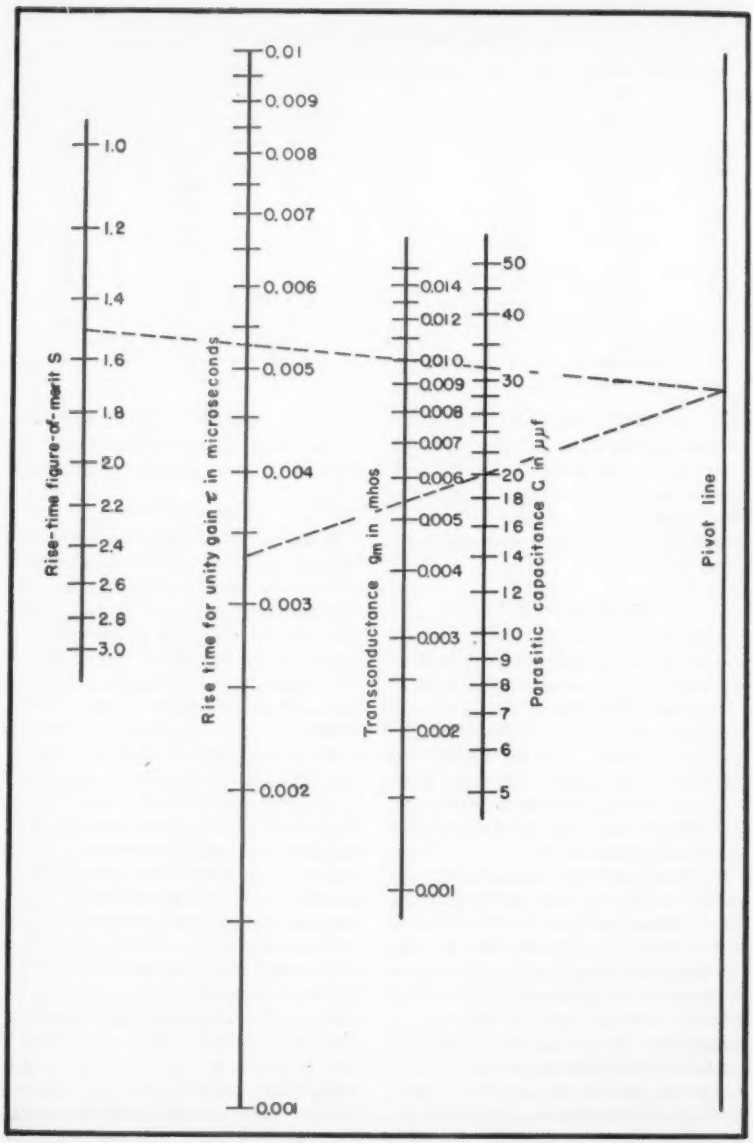


FIG. 6. Nomograph for computing τ, the rise time for unity gain. The broken lines illustrate the method of using the nomograph

involved in the design of the amplifier. This will be true for pulse amplifiers working out of an electronic detector of radiation that gives signals having an amplitude of about one millivolt or more.

Important properties of several types of tubes suitable for use in pulse amplifiers are given in the table, which lists nominal values of the transconductance, the plate current, the input and output capacitance, the rise time for unity gain (with $S = 1$), and a figure-of-merit for the tube as an output stage. The capacitance used in computing τ has been taken as the sum of the input and output capacitances for the tube under consideration, plus a nominal wiring capacitance of 5 $\mu\mu$f. In practical amplifiers it may be possible to reduce the wiring capacitance somewhat below this value; it is very easy to exceed it by a poor layout of parts. The values of transconductance and plate current can be increased somewhat over the values given in the table. An upper limit to both these quantities is set by the maximum permissible plate (or screen) dissipation of the tube.

The ratio $I_p/(C_0 + 10)$, which is given for each tube in the table, can be taken as a measure of the suitability of a particular tube as an output stage. A nominal capacitive load of 10 $\mu\mu$f is assumed to be connected in parallel with the output capacitance of the tube. If the capacitive load is as great as this, it is often desirable to employ a cathode-follower output stage following the final amplifying stage. Such a stage is particularly suitable for a pulse amplifier designed for nuclear applications, since the high-level stages can be asymetrically biased to favor the amplification of pulses of one polarity, with the number of inversions of pulse polarity chosen to give a positive-going output pulse.

The writer has found that the design of a pulse amplifier is carried out most expeditiously by starting with the output stage and its assumed capacitive load, and working back through the input stage to the electronic detector of radiation. Each stage in turn is designed to deliver a sufficiently great signal to the following stage, using in each case the plate-load resistance necessary to give the desired rise time. Some additional design considerations, involving the gain control and the pulse-shaping networks, are described in reference *2*.

BIBLIOGRAPHY

1. W. C. Elmore, *J. Applied Phys.* **19**, 55–63 (1948)
2. W. C. Elmore, NUCLEONICS **2**, No. 2, 4–17; No. 3, 16–36 (1948)
3. G. E. Valley, Jr., H. Wallman, "Vacuum Tube Amplifiers," pps. 67 and 75 (McGraw-Hill Book Co., Inc., New York, 1948)

NOW undoubtedly the greatest immediate threat to the further progress of the human mind is the *unequal development* of the branches of knowledge, *i.e.*, the relatively high degree of our control over inorganic nature, combined with our still very rudimentary knowledge of biology and genetics, and with the complete absence of a scientific psychology and sociology. The more obvious danger of this unequal development of our knowledge lies in the fact that human control over inorganic nature provided men with means of destroying life and property on a grand scale; whilst the present emotional makeup of men, and their extraordinarily crude and inept forms of social organization, make it only too likely that these means will be used.

—C. D. Broad, "The Mind and Its Place in Nature" (Kegan Paul, 1929)

Effect of Soft X-Rays on Vitamins (Niacin, Riboflavin, and Ascorbic Acid)

Results of tests in which pure solutions of niacin, riboflavin, and ascorbic acid were exposed to soft X-rays produced at 50 kv. These vitamins were irradiated separately in stock solutions, in more dilute concentrations, and in mixtures of both ascorbic acid and niacin and ascorbic acid and riboflavin

By BERNARD E. PROCTOR* and SAMUEL E. GOLDBLITH†

Department of Food Technology
Massachusetts Institute of Technology, Cambridge, Massachusetts

THIS REPORT relates to the vitamins niacin, riboflavin, and ascorbic acid as they are affected by irradiation with soft X-rays produced at 50 kv.

Soft radiations, because of their limited ability to penetrate matter, seem destined to be of less interest than high-voltage X-rays or cathode irradiation in the processing of foodstuffs (*6*, *7*). However, a comparison of the effects of 50-kv radiations with those of the supervoltage radiations on vitamins presents interesing findings, worthy of note.

There are no published reports on the effects of relatively low-voltage X-rays on either niacin or riboflavin. Anderson and Harrison (*1*) have studied the effects of X-rays produced at 185 kv on very dilute solutions of ascorbic acid, and other investigators (*3*, *8*) have studied the effects of X-rays on thiamine and *p*-aminobenzoic acid. These studies, however, were made in different laboratories with the use of different sources of radiation. A study of the relative radiosensitivities of certain of the vitamins under identical conditions, with the use of the same equipment, therefore, has possible interest as a means of interpreting differences in the actions of these different types of irradiation.

Equipment

Soft X-rays were produced by a Machlett beryllium window tube of a Wappler roentgen apparatus operating at a peak of 50 kv.‡ The output of this tube is extremely high, of the order of 165,000 roentgens (r) per minute of unfiltered radiation at a distance of 5 cm from the target. The X-ray spectrum produced varies from 0.25 to approximately 4.4 A.U. with a maximum intensity at 1.7 A.U. To cut off the longer wavelength portions of the spectrum and thereby increase the half-value layer, filtration with aluminum foil (0.0026 inch in thickness) was used.

The X-ray spectra of the unfiltered and the filtered radiations are presented in Fig. 1.

The half-value layer for water of the filtered radiations is 1.8 mm. A dose-

* Director, Samuel Cate Prescott Laboratories of Food Technology.
† Research Associate, Samuel Cate Prescott Laboratories of Food Technology.

‡ The authors are indebted to the Machlett Laboratories of Springvale, Conn., for placing the X-ray equipment at their disposal.

rate of 14,890 r per min was obtained by using the filtered radiations at a distance of 10 cm from the target. The sample was 1.52 mm thick. The cone of radiation obtained was large enough to cover a 1-ml sample in a stainless steel dish 29 mm in diameter, 10 cm from the target.

The dishes used for irradiation were small, stainless-steel cylinders, 29 mm in diameter and 8 mm high. A cover of aluminum foil was used, 0.00065 inch thick, which served as part of the total filtration.

Methods of Assay

Niacin was measured chemically by a modification of the Mueller and Fox cyanogen bromide method (*5*).

Riboflavin was measured fluorometrically in a Pfaltz and Bauer fluorophotometer, as described by the Association of Vitamin Chemists (*2*).

Ascorbic acid was measured photometrically according to the method described by Hochberg, Melnick, and Oser (*4*).

Experimental

All three vitamins were of U.S.P. grade. A stock solution of each of the three was prepared, having a concentration of 100 micrograms of the vitamin per milliliter of solvent. These vitamins, in stock solutions or more dilute concentrations, were irradiated separately and in mixtures of ascorbic acid with either niacin or riboflavin.

When the vitamins were irradiated separately, absolute alcohol was used as the solvent for niacin, distilled water acidified with glacial acetic acid (two drops per 500 ml) for riboflavin (*p*H 4.0) and 0.25% oxalic acid for ascorbic acid. When mixtures of ascorbic acid with either niacin or riboflavin were irradiated, the solvent used was 0.25% oxalic acid in all instances.

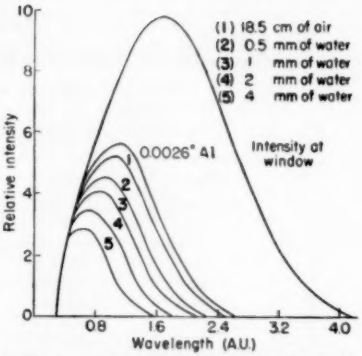


FIG. 1. Theoretical absorption in water of radiations of AEG-50 tube at 18.5 cm of air filtered by 0.0026 inch of aluminum

To determine whether these vitamins are more radiosensitive in less concentrated solutions, dilutions of the stock solutions were made, as needed, with distilled water (niacin and riboflavin) or oxalic acid (ascorbic acid).

In all instances, 1-ml samples of the various solutions were used for irradiation, the target distance was 10 cm, the current 50 ma (milliamperes), and the rate of X-ray dosage 14,890 r per min.

Samples of niacin in concentrations of 50 and 10 micrograms per ml were irradiated by soft X-rays for total dosages ranging from 50,000 up to 500,000 r (Table 1). To determine whether there was any protective action when mixtures of niacin and ascorbic

EDITOR'S NOTE: This report is the third of a series regarding the effects of ionizing radiations on some of the chemical compounds contained in foods. The two previous reports, by the same authors, were concerned with the effects of irradiation by hard X-rays produced at relatively high voltages on niacin, riboflavin, and carotene. (See references *6* and *7* in the bibliography.)

TABLE 1

Effect of X-Rays Produced at 50 kv on Solutions of U.S.P. Niacin

Volume irradiated..... 1 ml
Current..... 50 ma
Target distance..... 10 cm

Sample No.	Time of Irradiation sec	Dosage r	Concentration of Niacin Before Irrad. γ/ml	Concentration of Niacin After Irrad. γ/ml	Retention of Niacin %
1	202	50,000	50	49.5	99
2	404	100,000	50	51	100
3	606	150,000	50	50	100
4	807	200,000	50	50	100
5	1614	400,000	50	51	100
6	606	150,000	10	10	100
7	1209	300,000	10	10	100
8	1612	400,000	10	7.2	72
9	2015	500,000	10	6.25	62.5

acid are irradiated, samples of niacin (10 micrograms per ml) and of ascorbic acid (500 micrograms per ml) were irradiated separately and in mixture by X-rays produced at 50 kv for a total dosage of 400,000 r (Table 4).

Samples of riboflavin in concentrations of 100, 50, 20, and 10 micrograms per ml were irradiated for total dosages of soft X-rays ranging from 100,000 to 500,000 r (Table 2). To determine the relative radiosensitivities of riboflavin and ascorbic acid when irradiated alone and when mixed together, samples of riboflavin (10 micrograms per ml) in aqueous solution and in 0.25% oxalic acid and samples of ascorbic acid (500 micrograms per ml) in 0.25% oxalic

TABLE 2

Effect of X-Rays Produced at 50 kv on Aqueous Solutions of U.S.P. Riboflavin

Volume irradiated..... 1 ml
Current..... 50 ma
Target distance..... 10 cm

Sample No.	Time of Irradiation sec	Dosage r	Concentration of Riboflavin Before Irrad. γ/ml	Concentration of Riboflavin After Irrad. γ/ml	Retention of Riboflavin %
10	403	100,000	50	50	100
11	1007	250,000	50	44.8	89.6
12	1612	400,000	50	27.9	55.8
13	2015	500,000	50	15.8	31.6
14	2015	500,000	100	54.7	54.7
13	2015	500,000	50	15.8	31.6
15	407	100,000	20	11.16	55.8
16	407	100,000	10	3.24	32.4

TABLE 3

Effect of X-Rays Produced at 50 kv on Solutions of U.S.P. Ascorbic Acid

Volume irradiated..... 1 ml
Current..... 50 ma
Target distance..... 10 cm
Solvent..... 0.25% oxalic acid

Sample No.	Time of Irradiation min	Time of Irradiation sec	Dosage r	Concentration of Ascorbic Acid Before Irrad. γ/ml	Concentration of Ascorbic Acid After Irrad. γ/ml	Retention of Ascorbic Acid %
17	..	40.3	10,000	100	98.0	98.0
18	1	2	15,000	100	96.4	96.4
19	1	40.7	25,000	100	85.6	85.6
20	3	21.6	50,000	100	68.7	68.7
21	5	2.1	75,000	100	52.0	52.0
22	10	4.8	150,000	100	19.8	19.8
23	13	27	200,000	100	3.53	3.53
24	..	40.3	10,000	50	43.65	87.3
25	1	40.7	25,000	50	35.0	70.0
26	3	21.6	50,000	50	22.1	44.2
27	5	2.1	75,000	50	13.2	26.4
28	6	43.2	100,000	50	8.55	17.1
28	6	43.2	100,000	50	8.55	17.1
29	6	43.2	100,000	100	37.0	37.0
30	6	43.2	100,000	500	325.0	65.0

acid were irradiated separately by 100,000 r of soft X-rays, and a mixture of the two vitamins in oxalic acid was irradiated by a like total dosage (Table 4).

Samples of the stock solutions of ascorbic acid (100 micrograms per ml) and of solutions of varying concentrations (50, 100, and 500 micrograms per ml) were irradiated by soft X-rays for total dosages of from 10,000 to as high as 100,000 or 200,000 r (Table 3). Assays for reduced ascorbic acid were made after irradiation.

Discussion of Results

Niacin in concentration of 50 micrograms per ml underwent no destruction when irradiated by soft X-rays produced at 50 kv for total dosages of from 50,000 up to and including 400,000 r (Table 1). When niacin of this same concentration was irradiated by hard X-rays produced at 3,000 kv, the destruction of the vitamin began at a total dosage of approximately 75,000 r; at a dosage of 500,000 r, the destruction amounted to 66% (*6*). These data indicate that, on the basis of equal total dosages and equal concentrations, the destructive effect on niacin of 3,000-kv X-rays is far more pronounced than that of X-rays produced at 50 kv.

When niacin in a concentration of 10 micrograms per ml was irradiated by the soft X-rays, there was no destructive effect at dosages of 150,000 and 300,000 r. At a dosage of 400,000 r, a loss of 28% of the niacin was observed and, at a dosage of 500,000 r, a loss of 37.5% was observed (Table 1).

When niacin of the same concentration (10 micrograms per ml) was irradiated by X-rays produced at 3,000 kv for a total dosage of 250,000 r, there was a loss of 70% of the niacin (*6*).

This comparison again illustrates the greater destructive effect of hard X-rays on niacin in pure solution as contrasted with the effect of the soft X-rays. Furthermore, the fact that irradiation by soft X-rays at 400,000 r did not cause any destruction of niacin in a concentration of 50 micrograms per ml, whereas it caused a 28% destruction when the concentration was lowered to 10 micrograms per ml is suggestive of a "dilution effect" and indicative of the indirect action of the soft X-rays on this vitamin.

When samples of niacin in aqueous solution and in oxalic acid solution at a concentration of 10 micrograms per ml, a sample of ascorbic acid in oxalic acid at a concentration of 500 micrograms per ml, and a mixture of the two vitamins at these two concentrations (in oxalic acid) were irradiated by soft X-rays for a dosage of 400,000 r, the losses of the vitamins (Tables 1 and 4) were as follows:

Sample	*Loss of Niacin*	*Loss of Ascorbic Acid*
Niacin alone		
Aqueous solution	28 %	
Oxalic acid solution	66.5%	
Ascorbic acid alone		58.4%
Niacin + ascorbic acid	86 %	28.2%

The above comparison illustrates the protective action of the niacin on oxalic acid and ascorbic acid. There was a greater destruction of the ascorbic acid when irradiated alone than when irradiated in the presence of niacin. The same type of results was noted previously (*6*) when niacin and ascorbic acid, separate and mixed, were irradiated by hard X-rays produced at 3,000 kv.

From these data, which show the protective action of niacin toward ascorbic acid and the result of dilution of niacin in solution, it would appear that niacin is destroyed by soft X-rays by an indirect action.

Although niacin *per se* is more radioresistant than ascorbic acid, yet when it is irradiated in mixture with ascorbic acid in concentrations of 10 and 500 micrograms per ml, respectively, the niacin protects the ascorbic acid.

Destruction of riboflavin in a concentration of 50 micrograms per ml began at a dosage of soft X-rays between 100,000 and 250,000 r, and at 500,000 r the destruction amounted to approximately 68% (Table 2). Although riboflavin is somewhat resistant to soft X-rays, it is not nearly so resistant as niacin. In previous work (*7*) an 85% destruction of an aqueous solution of riboflavin at a concentration of 50 micrograms per ml was noted when the vitamin was irradiated by 250,000 r of X-rays produced at 3,000 kv. With the same dosage of X-rays produced at 50 kv, the destruction of riboflavin of this same concentration was only 10.4%. A similar difference between the destructive effects of hard and soft X-rays was noted, as mentioned previously, when niacin was irradiated by both types of radiation.

From the data in Table 2 it is apparent that, upon exposure to soft X-rays, riboflavin conforms to the theory of the indirect action of X-ray irradiation and is more radiosensitive in dilute solutions than in more concentrated ones.

When riboflavin in a concentration of 10 micrograms per ml was irradiated by 100,000 r of soft X-rays, there was a 68% loss of the vitamin in aqueous solution and only a 27% loss in oxalic acid solution. When ascorbic acid (500 micrograms per ml) was added to the oxalic acid solution of riboflavin and the mixture was given the same dosage of soft X-rays, there was no loss of riboflavin. Hence it would seem that riboflavin is protected from the X-rays by the oxalic acid and the ascorbic acid, which presumably compete successfully

Table 4

Effects of X-Rays Produced at 50 kv on Solutions of Niacin and Riboflavin Irradiated Separately and Combined with Ascorbic Acid

Volume irradiated..... 1 ml
Current..... 50 ma
Target distance..... 10 cm

Series and Sample No.	Concentration of Niacin		Concentration of Riboflavin		Concentration of Ascorbic Acid		Retention of		
	Before Irrad. γ/ml	After Irrad. γ/ml	Before Irrad. γ/ml	After Irrad. γ/ml	Before Irrad. γ/ml	After Irrad. γ/ml	Niacin %	Riboflavin %	Ascorbic Acid %
*Series I**									
31	10	3.35	..	.....	...	...	33.5		
32	10	1.4	..	.....	500	359	14.0	....	71.8
33	..	....	..	.....	500	208	....	....	41.6
Series II†									
16‡	..	....	10	3.24	...	...	....	32.4	
34§	..	....	10	7.26	...	...	....	72.6	
35§	..	....	10	10	500	421	....	100.0	84.2
30§	..	....	..	.....	500	325	....	.....	65.0

* Time of irradiation was 1612 sec; dosage of X-rays was 400,000 r; all solutions were made with 0.25 % oxalic acid
† Time of irradiation was 403 sec; dosage of X-rays was 100,000 r
‡ Aqueous solution
§ In 0.25 % oxalic acid

for the molecules of "activated water" or some activating agent that is produced by irradiation.

Furthermore, the ascorbic acid also was protected from the X-rays when it was irradiated in the presence of oxalic acid and riboflavin (Table 4). Here is an apparent example of the complex interaction of three compounds which were competing for the molecules of "activated water" produced by X-rays, each of which was related to the amount of destruction of the other compounds.

Ascorbic acid is extremely radiosensitive in dilute solution. Anderson and Harrison (*1*) found that when the initial concentration of ascorbic acid was approximately 4 micrograms per ml, half of this vitamin was destroyed upon exposure to 5,500 r of X-rays produced at 185 kv. The data of this present investigation (Table 3) show that irradiation with 75,000 r of soft X-rays caused a destruction of approximately 50 % of the ascorbic acid when irradiated in a concentration of 100 micrograms per ml and a destruction of 74 % when irradiated in a concentration of 50 micrograms per ml. Further examples of the effect of dilution can be seen from other data in Table 3. The destruction of ascorbic acid, like that of the other vitamins studied, was more complete in the more dilute solutions.

The effect of a "protective action" has been demonstrated above in the discussion of the results obtained with niacin and riboflavin. The mode of action of soft X-rays upon ascorbic acid appears to be indirect.

The relative radiosensitivities of niacin, riboflavin, and ascorbic acid are compared in Table 5. It is apparent that, of the three vitamins studied, ascorbic acid is the most radiosensitive and niacin the most radioresistant to soft X-rays. This also was found to be the case when these vitamins were

TABLE 5

Relative Radiosensitivities of Niacin, Riboflavin, and Ascorbic Acid When Exposed to X-Rays Produced at 50 kv

Compound	Dosage r	Concentration Before Irrad. γ/ml	Concentration After Irrad. γ/ml	Retention %
Niacin	400,000	50	50	100
Riboflavin	250,000	50	44.8	89.6
Ascorbic Acid	100,000	50	8.55	17.1

irradiated with hard X-rays produced at 3,000 kv (*6*, *7*).

Summary and Conclusions

1. The effects of X-rays produced at 50 kv on pure solutions of niacin, riboflavin, and ascorbic acid have been studied.

2. These ionizing radiations affected all three vitamins in accordance with the indirect action theory. Each vitamin was more sensitive to irradiation in higher dilution.

3. Ascorbic acid was the most radiosensitive of the three vitamins. Niacin was more radioresistant than riboflavin in pure solution.

4. Although niacin alone was more radioresistant than ascorbic acid, yet when a mixture of the two was irradiated with X-rays produced at 50 kv, there was greater destruction of the niacin and sparing of the ascorbic acid. Presumably the niacin competed more successfully for the molecules of activated water.

5. Riboflavin was protected by oxalic acid from the destructive effect of irradiation with X-rays produced at 50 kv and was protected even more so by ascorbic acid.

6. Ascorbic acid was protected from X-rays produced at 50 kv when it was irradiated in the presence of riboflavin and oxalic acid.

7. On the basis of equal total dosages of irradiation and equal concentrations of vitamins in solution, X-rays produced at 3,000 kv were far more destructive to niacin and to riboflavin than X-rays produced at 50 kv.

* * *

This report is the third of a series regarding irradiation studies conducted by the staff of the Department of Food Technology, Massachusetts Institute of Technology, with the assistance of grants-in-aid from the following organizations: American Can Company, Maywood, Ill.; Dow Chemical Company, Midland, Mich.; Nestlé Co., New York, N. Y.; Pillsbury Mills, Inc., Minneapolis, Minn.; Standard Brands, Inc., New York, N. Y.; Wilson & Company, Chicago, Ill.

The authors are indebted to Professor John G. Trump, the late Mr. Arthur M. Clarke, and Mr. Kenneth A. Wright, of the Department of Electrical Engineering, Massachusetts Institute of Technology, for their cooperation in making the Trump generator available for this study.

BIBLIOGRAPHY

1. R. S. Anderson, B. Harrison. The quantitative effect of X-rays on ascorbic acid in simple solution and in mixtures of naturally occurring compounds. *J. Gen. Physiol.* **27**, 69 (1943)
2. Association of Vitamin Chemists. "Methods of Vitamin Assays," p. 109–110. (Interscience Publishers, Inc., New York, 1947)
3. C. E. Dunlap, F. C. Robbins. The effect of roentgen rays, radon, and radioactive phosphorus on thiamine chloride. *Am. J. Roentgenol. Radium Therapy*, **50**, 641 (1943)
4. M. Hochberg, D. Melnick, B. L. Oser. Photometric determination of reduced and total ascorbic acid. *Ind. Eng. Chem., Anal. Ed.* **15**, 182 (1943)
5. A. Mueller, S. H. Fox. Chemical determination of niacin. *J. Biol. Chem.* **167**, 291 (1947)
6. B. E. Proctor, S. A. Goldblith. Effect of high-voltage X-rays and cathode rays on vitamins (niacin). NUCLEONICS **3**, No. 2, 32 (1948)
7. B. E. Proctor, S. A. Goldblith. Effect of high-voltage X-rays and cathode rays on vitamins (riboflavin and carotene). NUCLEONICS **5**, No. 2, 50 (1949)
8. I. C. C. Tchaperoff. Determination of the effect of irradiation by X-rays on p-amino benzoic acid using Clostridium acetobutylicum for assay. *Can. J. Research* **24E**, 49 (1946)

Retention of Radon by the Mouse—I

EXPERIMENTAL DETERMINATION OF BIODECAY AND ENERGY ABSORBED*

Radon in equilibrium with its short-lived decay products presents a convenient alpha-ray source for study of biologic effects of these ionizing particles in laboratory animals and for comparison with similar effects produced by other ionizing radiations. To calculate the energy absorbed following radon administration, elimination rate must be found

By JOANNE WEIKEL HOLLCROFT and EGON LORENZ

National Cancer Institute, Bethesda, Maryland

SHORTLY AFTER the discovery of radon, many papers appeared in the literature describing its therapeutic uses, such as in baths, by inhalation, or by the drinking of radon water. The early applications of radon are summarized by Lazarus (*1*), Falta (*2*), and Gudzent (*3*). Later, more careful studies were made on the uptake and elimination of radon in patients, notably by Markl (*4*) and by St. Meyer (*5*). Markl calculated the alpha particle energy, and Fernau and Schmereker (*6*) calculated the total absorbed energy from St. Meyer's elimination data. No intensive animal experiments along this line have been reported, however.

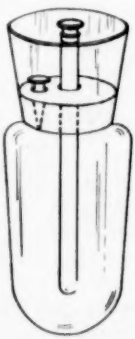
This paper deals with the elimination of radon from mice following administration of an aqueous radon solution, *i.e.*, biodecay and determination of the energy absorbed by the animal from the disintegration of the radon and its subsequent short-lived decay products.

Experimental Procedures

The radon used in the present experiments was obtained from a solution of $RaBr_2$ enclosed in a glass container in connection with a vacuum system. For details, see Fig. 1 on next page.

The other gases formed by alpha bombardment of the $RaBr_2$ solution were pumped off; the collection bulb was then removed from the system and an air free solution of 0.1% sodium citrate drawn into the bulb. With care in freezing out the radon and in pumping off the unfrozen gases, 75% to 80% of the total radon formed was obtained in solution.

Since for purposes of the experiment no further purification was necessary, this radon solution was transferred directly to a glass storage bottle, as illustrated here, the stoppers of which were covered with citrate solution. With this arrangement some of the solution could be removed from time to time with a syringe inserted through the hole shown at the left; the liquid withdrawn was



* This paper is based on work performed under contract W-31-109-eng-38 for the Manhattan Project at the Argonne National Laboratory.

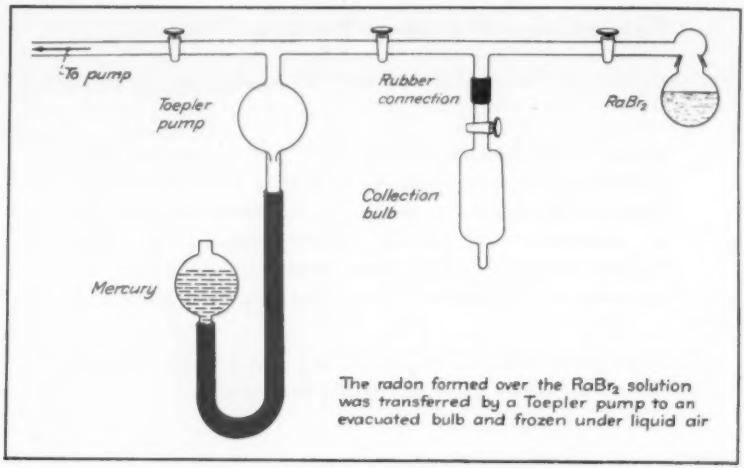

To pump
Toepler pump
Rubber connection
$RaBr_2$
Collection bulb
Mercury
The radon formed over the $RaBr_2$ solution was transferred by a Toepler pump to an evacuated bulb and frozen under liquid air

FIG. 1. Apparatus for the collection of radon

replaced by the citrate solution flowing through the center tube. In addition to its displacement function, the citrate kept the RaA, RaB, and RaC in solution and prevented their absorption on the sides of the glass storage bottle or syringe. The latter was demonstrated by repeated measurement of the several samples taken during each experiment.

In most experiments, however, the large stopper was removed and the required number of syringes filled immediately. When the syringes were filled in this way, they were all found to contain equal amounts of radon.

Two methods were used to study the elimination of the radon. First, groups of mice were killed at certain intervals (5, 10, 30, 60, 90, 120, 180 and 240 min) after radon administration and sealed in glass tubes. The RaC gamma rays were measured four hours later, when the remaining radon was in transient equilibrium with the RaC. The animals were killed by cervical dislocation to stop respiration promptly, so that the error in time was five seconds at the most.

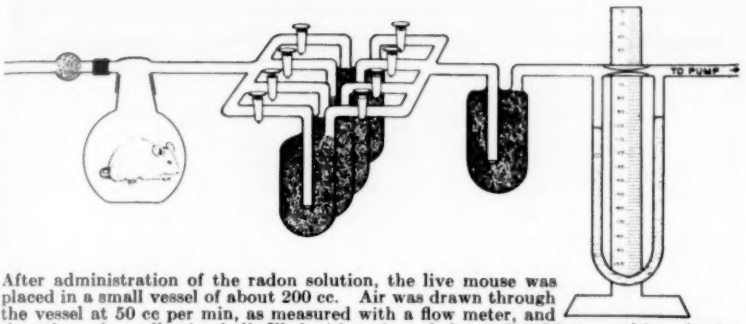
The second method utilized the fact that radon is quantitatively absorbed by activated charcoal at dry-ice temperature. For details, see Fig. 2.

The common second bulb seen in the illustration was also immersed in dry ice and served to collect any radon not previously absorbed. However, this proved unnecessary in practice as no radon was found in this bulb. The sampling bulbs were subsequently sealed off and the RaC gamma rays measured.

Measurements of the samples were made with single Geiger-Müller counters and also with multiple counters (*7*) in conjunction with a counting rate meter (*8*). Both the charcoal tubes and those containing the mice were the same size as ampoules filled with 25 cc of standard amounts of radium chloride solution which were used for comparison.* To absorb the soft gamma radiation, all measurements were taken through 3 mm of lead shield.

Preliminary studies were made with several strains of mice using different

* These standards were obtained from the National Bureau of Standards.



After administration of the radon solution, the live mouse was placed in a small vessel of about 200 cc. Air was drawn through the vessel at 50 cc per min, as measured with a flow meter, and then through a collection bulb filled with activated charcoal and immersed in a dry ice acetone mixture. By parallel arrangement of several such bulbs, a series of exhalation samples were obtainable at set intervals of time (5, 10, 15 and 30 min) after administration

FIG. 2. Apparatus for the adsorption of exhaled radon on charcoal

methods of administration. LAF_1 male and female mice three months of age and C3H female mice 2½ months of age were injected intraperitoneally with 0.5 cc radon solution. The concentration of the solution varied from about 1 mc/cc to 0.5 mc/cc. The amount remaining in the mouse was determined at 5, 10, 15, and 30 min after administration. Because of biological variations, the measurements varied widely within each group although the mice within the groups were inbred, of the same sex and approximately the same age. In an attempt to reduce the wide variation in breathing rate, strain A male and female mice were anaesthetized with urethan prior to intraperitoneal injection of the radon solution.

To study the role which body fat might play in the retention of radon, AYF_1 mice were used. In these the Y strain carries a yellow gene which is lethal when it occurs in the homozygous condition, but mice heterozygous for the gene are viable. The latter have a yellow coat color and a tendency to become obese. In mating strain A females with strain Y males a hybrid generation is produced in which approximately 50% have a yellow coat color and become obese and the rest have a brown coat color and no tendency to become obese.

To determine rate of elimination after oral administration, LAF_1 male and female mice 4 months of age and C3H male mice 2 months of age were fed radon solution by tube. In order to assess the influence of gastrointestinal conditions on the elimination of radon, one half of the LAF_1 mice were deprived of food for 18 hours and water for 4 hours before radon administration.

The final studies of radon retention after intraperitoneal and intravenous injection were made on strain A mice 3 to 4 months of age. In the intravenous studies female mice were used exclusively with the exception of one group of males used to check a possible sex difference in elimination. The intraperitoneal studies were made on both male and female mice.

Experimental Results

Since the early findings (Table 1) obtained with the charcoal absorption did not appear significantly different from those obtained by the other method, they were treated throughout the study as a single group. Although

TABLE 1

Amount	*Method of injection*	*Strain*	*Age in months*	*Sex*	*Number of animals for each observation*	*Special considerations*	5 min	10 min
0.5 cc	I.P.	LAF	3	♀	9		19.3±10.0	
0.5 cc	I.P.	LAF	3	♂	9		16.3±7.6	
0.5 cc	I.P.	C3H	2½	♀	9		19.3±15.6	
0.5 cc	I.P.	YAF_1	5	♀	7	yellow 40–45 gm		
0.5 cc	I.P.	YAF_1	5	♀	7	brown 25–30 gm		
0.5 cc	I.P.	A	3½	♂	9	anaesthetized	60.2±21.2	
1.0 cc	I.P.	A	4½	♀	4	anaesthetized	57.2±26.8	40.4±25.4
0.5 cc	Subcu	LAF_1	3½	♀	3		34.3±5.1*	
1.0 cc	Subcu	A	3½	♀	5			
0.5 cc	Oral	LAF_1	4	♀	3	deprived food and water		
0.5 cc	Oral	LAF_1	4	♀	3			
0.5 cc	Oral	LAF_1	4	♂	2	deprived food and water		
0.5 cc	Oral	LAF_1	4	♂	2			
0.5 cc	Oral	C3H	2	♂	3			
0.5 cc	I.V.	YAF_1	3½	♂	3	brown 24–27 gm		
0.5 cc	I.V.	YAF_1	3½	♂	5	yellow 34–37 gm		

* Standard deviation:

frequently too few animals in each group were observed to draw many conclusions, nevertheless, the following observations can be made.

The elimination rate, at least for the first hour differed with different routes of administration and, in general, was higher for intravenous than for the other methods of administration. An idea of the spread of the points can be obtained by the standard deviations accompanying the percent of radon retained. The amount of fat on the animal is a large factor in retention following intraperitoneal injections but a small one in retention following intravenous injection. Since the anaesthetized mice showed as great a variation as did the others, the urethan sufficed only to slow radon exhalation.

The composite results of the more intensive intraperitoneal and intravenous experiments (Table 2) provide a suitable basis for the analysis of the time curves of elimination (Fig. 3) and calculation of the radiation dose.

Retention of Radon by Mice Following Different Routes of Administration

% Radon retained at					
15 min	30 min	60 min	90 min	120 min	240 min
6.53±14.2*	0.375±0.333				
3.43±1.96	0.877±0.409				
0.478±0.391	0.192±0.039				
	25.3±7.8				
	2.23±0.18				
12.5±5.3	12.6±6.0				
31.1±23.1	13.9±13.1	3.2±3.7			
	1.19±0.34	0.399±0.310			
		4.23±2.1		0.281±0.270	0.0045±0.0008
	11.63±3.35	5.19±1.51	2.49±0.42	1.605±0.125	
31.7±8.1	19.2±5.9	7.56±2.09		0.219±0.068	
	29.6±4.6	5.57±4.41		4.95±0.06	
	20.6±10.3	6.16±3.57		0.764±0.000	
16.1±9.1	9.35±0.55	2.47±0.10	2.82±2.17	0.788±0.171	
	0.21±0.10				
	0.712±0.84				

Calculated as $\sigma = \sqrt{\frac{(\Sigma x)^2 - \frac{\Sigma x^2}{N}}{N-1}}$

For dosage determination, it is of primary interest to know the number of radon atoms disintegrating in the animal with a certain degree of accuracy. This number is given by

$$D = N\lambda \int_0^\infty e^{-\lambda t} f(t)\, dt$$

where N is the number radon atoms originally injected and $Nf(t)$ is the amount present at any time. The factor $f(t)$ is dependent on the absorption of the radon by the tissues, as well as on the breathing and pulse rates and therefore differs greatly with the method of administration; it can be found by a graphic method of analysis such as that described by Smith and Morales (*9*). By this method the equation for the retention after intravenous injection was found to be

$$f(t) = 91.82e^{-2.3t} + 7.8e^{-.062t} + 0.38e^{-.012t}$$

and that for intraperitoneal injection

$$f(t) = 80e^{-0.184t} + 17e^{-.0357t} + 3e^{-.022t}$$

TABLE 2

Radon Retention in Strain A Mice

Intraperitoneal Injection				*Intravenous Injection*			
Time Minutes	*Number of Animals*	*% Rn*	*Standard Deviation*	*Time Minutes*	*Number of Animals*	*% Rn*	*Standard Deviation*
5	29	43.4	14.8	5	10	6.014	2.24
10	18	34.8	21.6	10	10	4.035	1.24
15	27	17.2	11.0	15	6	3.13	1.41
20	3	12.7	7.3	30	17	1.59	1.02
30	27	6.4	3.9	60	20	0.387	0.246
60	17	2.87	2.36	120	16	0.103	0.0178
120	12	0.224	0.435	180	12	.043	.0225
240	5	0.022	.005	240	4	.021	.005

Depending upon the number and relative distributions of the experimental points, however, the constants in the above equations may be subject to considerable error. A comparison was therefore made between the curves so predicted and those computed by another method, namely that described by Cornfield (*10*). For the latter, the integral was divided up into small intervals and the sum taken:

$$D = N\lambda \sum_j \int_{t_j}^{t_{j+1}} e^{-\lambda t} f(t)\, dt$$

where $f(t) = a_j e^{-b_j t}$ is evaluated from the experimental data at time 5, 10, 15, 30, 60, 120, 240 min.

In case of the intravenous injection, D was calculated for the average to be $2.50 \times 10^{-4} N$ by the method of summation and $2.45 \times 10^{-4}\ N$ by the use of the equation fitted by the Smith-Morales method. The agreement, therefore, is within 2%, which appears to fall well within the error of estimate, namely 7.8%, obtained for D when the latter is calculated in terms of the number of observations made (*10*). In the case of the intraperitoneal injection, the respective values of D were calculated to be $1.30 \times 10^{-3} N$ and $1.35 \times 10^{-3} N$, a difference of about 4%.

The method of summation was also used to estimate the number of radon atoms disintegrating when either the maximum or minimum values of retained radon were taken. For the intravenous injections, this maximum was $4.48 \times 10^{-4} N$, or 63% more than the average number of radon disintegrations, and the minimum was $1.43 \times 10^{-4} N$, or 48% less than the average. For the intraperitoneal injections, the extreme cases gave a maximum of $2.50 \times 10^{-3} N$, or 90% more than the average, a minimum of $9.24 \times 10^{-4} N$, or 20% less than the average.

Calculation of Radiation Dose

Because the radon is eliminated so rapidly by exhalation and only a small percent of the radon atoms disintegrate in the animal, a tremendous amount of radon would be necessary to provide energy sufficient to produce readily noticed biologic changes, if radon alone is given. Therefore, all injections were made with radon in equilibrium with its short lived-decay products; hence, the dose mainly originates from the RaA, RaB, RaC and RaC′. From the known energies of the α and β-particles which these elements emit, the energy absorbed can be readily calculated.

If per gram of mouse M millicuries of radon in equilibrium with its decay products are injected into an animal, $9.91 \times 10^{9} M$ atoms of RaA per gm,

$8.88 \times 10^{10}M$ atoms RaB per gm, $6.44 \times 10^{10}M$ atoms RaC per gm, and $52.2M$ atoms RaC′ per gm are also injected. The energy from the complete disintegration of these short-life decay products totals $2.39 \times 10^{6}M$ ergs per gm tissue. This assumes use of an average energy of the β-particles equal to one-third maximum energy.

In addition, however, the radon decaying through the subsequent stages also contributes to the dose. The total number of radon atoms disintegrating in the mouse after intraperitoneal injection was $1.30 \times 10^{-4}N$ or $2.38 \times 10^{10}M$ atoms per gm tissue as estimated from the average radon retention. In this case the ionizing radiations from the radon and its subsequent decays through RaC′ add $7.8 \times 10^{5}M$ ergs per gm to the dose, bringing the total energy absorbed in the mouse to $3.17 \times 10^{6}M$ ergs per gm. Likewise the average radon retained after intravenous injection contributed $1.495 \times 10^{5}M$ ergs per gm, making the total energy absorbed amount to $2.54 \times 10^{6}M$ ergs per gm. Hence the retained radon and its subsequent decay products contribute 24.6% to the total energy in the case of intraperitoneal injections and only 5.9% of the total energy in the case of intravenous injections.

The spread in the absorbed energy can be obtained from the number of disintegrations as calculated from the extreme values of the retained radon. When the energy calculated from these extreme values of the radon retained is added to the energy of the short-lived decay products, it is found that following intraperitoneal injections the maximum energy absorbed is about 29% more than the average and the minimum is about 23% less than the average; following intravenous administration, however, the maximum is about 4% more than the average and the minimum is about 2% less than the average energy absorbed. Further, the error in the estimation of the average energy absorbed after intravenous injection can be determined from the error in the estimate of radon disintegrations, D, that is, 7.8% as given above. Since the radon contributes 5.9% of the total energy absorbed following intravenous injection, the error in the total becomes about 0.5%.

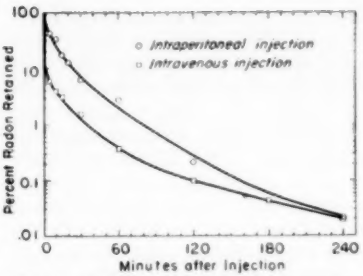


FIG. 3. Retention of radon in the mouse

Discussion

As was expected both from the nature of the system and the shape of the curves, the most reasonable empirical expression for the retention appeared to be an exponential sum. The number of points taken along the time axis limited the number of determined biologic decay constants to three. An additional constant might have been determined for the initial decay if the curve as a whole had been considered; however, the part of the curve from 0 to 5 minutes was arbitrarily drawn. The curves differ greatly in slope during the first two hours but approach each other during the third and fourth, showing that the radon is not trapped in either case and that the end elimination processes are alike.

Judging from the studies of Smith and Morales (*11*) on inert gas exchange, the first constant (2.3) found for the intravenous retention curve largely

represents the rate at which the radon is being eliminated from the vascular fluid spaces. The second (0.06) and third (0.012) probably reflect the rate at which it is being removed from "aqueous tissues" or muscle and the fat depots. From this it would seem that the radon had reached maximum concentration in the tissues almost immediately, a circumstance which is very improbable especially in the case of the highly absorbing but poorly vascularized fat regions. Further indications of this failure to reach equilibrium may be adduced from the relative magnitudes of the coefficients. For an equilibrium to have been achieved the coefficients of the second and third terms should have reached much higher values than those obtained, if only by reason of the high fat solubility of radon (see below).

In the expression for the retention following intravenous injection, the initial constant of 2.3 is large in comparison with the elimination constant of 0.66 as found by Underwood and Diaz (*12*) who worked with dogs. Although the two are not strictly comparable since Underwood and Diaz did not analyze their curves beyond the first 5 min, the difference in constants may be indicative of the difference in species. The initial constant should depend upon the efficiency of the cardovascular and respiratory systems since the radon is eliminated mainly by exhalation. The pulse rate of mice varies greatly and, as measured by Oppenheimer (*13*), is 500 to 800 per min while in dogs it is from 70 to 80 per min. Likewise, the breathing rate is different in the two species.

Underwood and Diaz found no variation in elimination rate when either cardiac output or pulse rate were varied. However, in the present study, the mice anaesthetized with urethan showed a definite decrease in radon elimination; this may be attributable to a reduction in lung ventilation rate or circulation time, although urethan is reported not to decrease the pulse rate (*13*).

The constants in the expression for retention following intraperitoneal injections are even more difficult to evaluate as considerable time is required for the radon to be absorbed from the peritoneal cavity. They perhaps can be considered best as a complex sum of the elimination and absorption constants. At any rate they too are governed mainly by the interaction of radon with the blood and various tissue components.

The use of the intraperitoneal injections introduced a process of radon absorption from the peritoneal cavity by the blood which was an additional process to those taking place following intravenous injections. It is perhaps noteworthy, however, that the coefficients of the two lower decay terms in the intraperitoneally injected groups are larger, especially the third term, than the corresponding values for the intravenous groups. This would appear to indicate a greater degree of fat time absorption in the former.

Similarly, the fact that obese yellow AYF_1 mice retained more radon than did the brown AYF_1 mice supports in some measure the suggestion that the last decay constant is governed by the gas exchange with the fatty tissue. As ardon is more soluble in fat than in water [it is 125 times more soluble in olive oil than in water at 37° C (*14*)], this radon retention in the fat is to be expected. It is also to be expected that the fat retention of radon would be greater when the radon is introduced into the peritoneal cavity for there the radon comes in contact with the abdominal fat and its absorption in this tissue does not depend on the blood supply to the tissue as a carrier.

In the dosage calculation, the energy from the gamma rays was not taken

into account because the total gamma-ray energy is only 1% of the total energy emitted by radon and its short lived decay products, and little of this gamma-ray energy is absorbed in the animal. Also the possibility that RaA, RaB, or RaC are excreted has been eliminated by measuring the RaC in the animal immediately after death.

In the studies done on strain A mice (following intravenous and intraperitoneal injections), it is seen that the total dose varies greatly with variations in radon retention after intraperitoneal injection but only slightly after intravenous injection. Because of the rapid exhalation of the radon immediately following intravenous injection, the radon contribution to the total is small so that variations do not matter. It is, therefore, advisable to inject the radon intravenously when studies of the radiation effect are to be made. For this reason the error in the estimation of D was calculated only for intravenous injections.

From the calculations of the radon contribution to the total radiation dose, it can be seen that a 50% error in the estimate of the radon retention will yield a 3% error in dose calculations. Therefore, to determine the radon disintegrations within 50%, only five animals are needed (*10*).

While the total energy absorbed in the mouse can be calculated accurately, the conversion of this energy into equivalent roentgens may be misleading. In making such a conversion it is assumed the radioactive elements are evenly distributed through the body; this is probably not true. The paths of alpha particle from Rn, RaA, RaC′ have ranges from 41 to 71 micra in tissue (*15*), and a localization of the radiation is probable. More studies must be done to determine not only the distribution of radon and its decay products throughout the body but also the LD 50–30 days for radon thus administered versus LD 50–30 days for externally administered X-rays.

BIBLIOGRAPHY

1. P. Lazarus. "Handbuch der Radiumbiologie und Therapie" (Bergmann, Wiesbaden, 1913)
2. W. Falta. "Die Behandlung innerer Krankheitem mit Radioaktiven Substanzen" (Springer, Berlin, 1918)
3. F. Gudzent. "Grundriss zum Studium der Radiumtherapie" (Urban and Schwarzenberg, Berlin-Wien, 1919)
4. J. Markl. Zu den Grundlagen der Balneologischen Radiumtherapie. Quantitative und Energetische Betrachtungen zum Problem der Physiologischan Dosierung der Emanationstherapie. *Strahlentherapie* **42,** 249 (1931)
5. S. Meyer. Physikalische Grundlagen zur Radiumemanationstherapie. *Sitzsber. Akad. Wiss. Wien., Math.-naturw. Klasse* **IIa, 138,** 557 (1929)
6. A. Fernau, H. Schmereker. Uber das Verbleiben Radioaktiver Substanz im Organismus bei Radium-Emanationstrinkkuren. *Strahlentherapie* **46,** 365 (1933)
7. J. Weikel, E. Lorenz. Excretion of Radium from the Mouse. *Radiology* **51,** 805 (1948)
8. E. Lorenz, J. Weikel, S. G. Norton. Counting Rate and Frequency Meter. *Rev. Sci. Instr.* **17,** 276 (1946)
9. R. E. Smith, M. F. Morales. On Theory of Blood—Tissue Exchanges, II. Applications. *Bull. Math. Biophysics* **6,** 133 (1944)
10. J. Cornfield. Retention of Radon by the Mouse—II. Method of Estimating Biodecay from Experimental Data. (To be published in NUCLEONICS)
11. R. D. Smith, M. F. Morales. The Physiological Factors which Govern Inert Gas Exchange. *Bull. Math. Biophysics* **7,** 99 (1945)
12. Newton Underwood, T. T. Diaz. A Study of Gaseous Exchange between the Circulatory System and the Lungs. *Am. J. Physiol.* **133,** 88 (1941)
13. E. Oppenheimer. Elektrokardiographische Studien an Kleinen Warmblutern. *Z. ges. exptl. Med.* **28,** 96 (1922)
14. J. H. Lawrence, W. F. Loomis, C. A. Tobias, F. H. Turpin. Preliminary Observations on the Narcotic Effect of Xenon with a Review of Values for Solubilities of Gases in Water and Oils. *J. Physiol.* **105,** 197 (1946)
15. D. E. Lea. "Actions of Radiations on Living Cells," p. 25 (Cambridge University Press, The MacMillan Company, New York, 1947)

Alpha-Particle Detection with Dental X-ray Film

By CARL C. SMITH*

MANY MATERIALS when irradiated by a beam of alpha particles react to produce beta rays. An investigation was undertaken to determine if this phenomenon could be practically utilized to record the presence of alpha radiation by dental X-ray film as usually supplied complete in its light-tight covering material.

Used in the experiment were Kodak type D.F.7 dental X-ray film packages which were irradiated with polonium alpha particles from crystals of polonium nitrate of approximately 1.0 millicurie activity. The work included the determination, by the use of a photographic emulsion, of the type of radiation induced, the measurement of the energy of the induced radiation, and the determination of the value of the recorded photographic densities as a method of approximate particle energy indication.

Experimental Technique

The dental X-ray film was wrapped in an outer parchment-like wrapper. Inside this package, it was enclosed between two black paper sheets with a lead-foil backing on the side remote from that normally exposed to the tube. The wrapper was some 254 microns thick and the black paper sections averaged 70 microns. Since particulate radiation on the front surface of the film package had to traverse some 324 microns of material, it was not anticipated that, with alpha radiation, any developed density on the film could be initiated by the alpha particles themselves.

On the assumption, however, that beta, gamma or neutron radiation could be induced by alpha particle bombardment of the outer film covering, the black paper sheet covering the front of the film could be regarded as a filter to the induced radiation. This suggested the possibility of introducing aluminum filters, in sufficient number, in place of the paper, to completely absorb the induced radiation and thereby furnish some indication of its energy.†

Each film was exposed for 3 hrs, at a distance of 1.5 cm from a smear of polonium nitrate crystals of approximately 1.0 millicurie activity; both exposure and development were precisely timed and all films in a batch were developed together at the temperature prescribed by the manufacturer. Following washing and drying, the developed densities were measured with a photoelectric comparison densitometer. The results are shown in the table and are plotted (triangular points) on semi-log paper in the figure.

A consideration of the form of this curve, which shows no indication of an asymptotic approach to the x-axis, leads to the conclusion that there is no gamma radiation induced and that it may reasonably be assumed the artificial activity is of a particle nature.

The characteristics of Kodak nuclear track emulsion, type N.T.A., were utilized to determine the nature of the induced radiation. This emulsion has high sensitivity to alphas, deuterons and

* Consultant, 1792 Dorchester Rd., Niagara Falls, Canada.

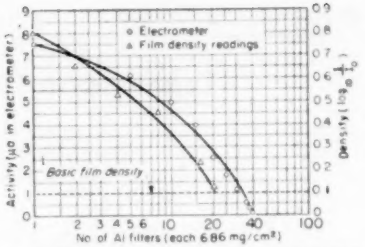
† L. E. Glendenin, NUCLEONICS **2**, No. 1, 26 (1948).

protons but is quite insensitive to beta and gamma radiation. Several plates coated with this emulsion were exposed to a solution of radium chloride from which the alpha radiation was filtered, the exposure being proportional to the relative activities of the radium solution and the polonium nitrate and to the relative sensitivities of the N.T.A. emulsion and dental film. Since these exposures failed to result in a developed density on the plates and since similar negative results were observed from exposure of this emulsion to the radiation induced from the dental film cover material, it was assumed that the induced activity consisted of beta particles. It was also ascertained that extended exposures of the dental film cover to polonium alpha radiation did not result in a delayed activity; the induced activity ceased with cessation of the incident alpha excitation.

It will be noted from the table that the developed density, under the cited experimental conditions with 3-hr exposure, and without aluminum filtration, was 0.9. The other densities recorded are for varying numbers of filters which were inserted, in the form of sheets of 0.001 in. aluminum foil, between the outer film cover material and the film. This operation was performed in the darkroom. It is clearly indicated by the curve that the limit of sensitivity of the film as an energy measuring medium is of the order of developed densities of 0.1 since the film base material with unexposed emulsion is of this order. The measurements (circled points) with electrometer were made to determine the degree of error to be expected by the use of the developed film densities as a measure of the maximum particle energies.

Photographic Determination of Energy of Induced Particles

Filter (mg/cm² Al)	*Photographic Density*
0	0.9
6.86	0.8
13.72	0.66
27.44	0.53
54.88	0.45
109.76	0.23
137.2	0.12
basic density of film	0.10



β^- radiation induced in cover material of Kodak D.F. 7 dental X-ray film by Po alpha radiation. Maximum β^- energy: electrometer measurement = 257.54 mg/cm² Al = 0.7 Mev; film density measurement = 144.06 mg/cm² = 0.46 Mev

Conclusions

The foregoing experimental data indicates that the following interpretations may reasonably be made:

1. Alpha-particle bombardment of the dental X-ray film cover material induces a beta activity during alpha excitation, but not a delayed activity, since artificial radiation is not perceptible when the alpha source is removed.

2. The induced beta activity is of such energy that excitation of the film emulsion, even through a number of filters of metallic foil, is quite definite and produced reasonably high photographic densities with relatively low exposures. The term exposure is used here in its usually implied sense as being the product of intensity and time.

3. Selective photographic emulsions may, in some cases, be used to advan-

(Continued on page 98)

Lebensform für das Monitor*

By EVAN C. EVANS, III
Gesund Physiks Department

THE MONITOR'S LIFE is a gay one. Daily he is greeted by the dyspeptic attitude laboratory personnel assume upon seeing a monitor. This attitude takes many malignant forms. There are those with an acute sense of humor who watch the monitor survey their cubicle with a disinterested leer and then, as he is about to leave, inform him coyly that he has failed to detect an 0.2 mr/hr source encased in 2 feet of Pb and stored in the bottom drawer of a safe. This leer is instantly recognized by the seasoned monitor, who can generally foil said wit by informing him that the background is high. There are others who express gloomy sentiments to the effect that the room was monitored yesterday and nothing has been moved since. This statement is driven home by adding that the meter is not accurate and besides it was calibrated with the window closed anyway. The discourse is generally concluded with reverent reminiscing on the delightfully contaminated conditions at Oak Ridge, etc. No effective counter-measures have been devised for this personage—the literature is still being searched, however. There are still others of extrovert tendencies who amuse the monitor with open manholes, precariously balanced beakers of fuming sulfuric acid, complex apparatus ingeniously maintained at a high potential, and other such mantraps. All this, of course, is very reassuring to the monitor and good cause for his usual joyous abandon.

The monitor is greatly assisted in many ways. His radiation hazard tags are thoughtfully removed and replaced by homemade signs in many foreign languages. This practice produces a pleasing variety of warnings of ambiguous significance. To save him extra work, spills are judiciously hidden by piling the area with heavy crates, by flooding, or simply by making it a red area (unfortunately this is no longer effective) There are, of course, a few uncooperative souls who inform Gesund Physiks that someone is baking a cake in the semi-hot lab muffle furnace. And there is always a fireman or two dashing about inquiring after his pants.

Although most lab personnel use survey meters as footstools, book ends, or sledge hammers, the monitor uses them in a rather unique fashion. When one can be found, he uses the instrument as a survey meter, a purpose for which it was most certainly not designed. The range switch is cleverly located so that the startled monitor either drops the instrument or dunks the probe into someone's prize solution while he attempts to switch to a higher scale. The leads to the probe hang in a long and graceful catenary. This causes mashed toes, mangled ears, and general melancholia due to dropping the meter when the probe leads catch on door knobs, gas outlets, own feet, rapidly passing small animals, prostrate

* Submitted by W. H. Sullivan, Scientific Director, Naval Radiological Defense Laboratory, San Francisco Naval Shipyard, San Francisco, Calif.

basic research workers, etc. However, armed with his meter and monitoring sheet the monitor sallies forth in quest of radiation. His purpose is poorly understood. Most people believe that he is an eccentric suffering from intense nomadic tendencies inherited from a distant Arabic ancestor. This belief is confirmed by the odd hieroglyphics he uses on the monitoring sheet—these have never been fully understood by anyone. The monitor's true purpose is to find a highly essential piece of equipment which has been contaminated beyond safe usage and thus bring all experimental progress to a screeching halt. When at last such an object is found, the news is heralded with wild hysteria and much quaffing of distilled water in the Gesund Physiks Dept.

Atomic Energy for Industry

Selected List of AEC Unpublished Declassified Documents of Particular Interest to Industry

THE LIST presented below is a selection of available and unpublished declassified documents which appear to be of value to industry. It is not a complete listing of declassified atomic energy information. The Atomic Energy Commission issues price lists and a journal of abstracts, which contain more complete listings of technical literature on nuclear science. Inquiries and requests for such material should be directed to the Document Sales Agency, P. O. Box 62, Oak Ridge, Tenn.

Documents marked "OTS" may be purchased from the Office of Technical Services, Dept. of Commerce, Washington, D. C.; those marked "AEC" may be purchased for the price indicated from the Document Sales Agency, P. O. Box 62, Oak Ridge, Tenn.

General Industrial and Laboratory Equipment

MDDC-548. General Engineering and Consulting Laboratory
Report on a Magnetic Drive Design for the Fercleve Corporation
AEC. $1.90

MDDC 932. E. G. Whitham
Camera Synchronizer
AEC. $0.15

MDDC-1293. Clinton Laboratories
Remote Control Pipette, Prints D2117, D2118, D2119, D2120, E2020
AEC. $1.40

MDDC-1507. Los Alamos
The Dry Box (Drawings)
AEC. $2.85

MDDC-1598. Los Alamos
Oscilloscope Camera Self Supporting (Drawings)
AEC. $2.45

Engineering, Lectures, Charts, Etc.

MDDC-33. M. C. Leverett
Nucleonics and the Chemical Engineering Curriculum
OTS. PB-52725

MDDC-223. J. L. McKibben
Nomographic Charts for Nuclear Reactions
AEC. $1.25

MDDC-378. S. K. Allison
Elementary Pile Theory
OTS. PB-50935
AEC. $0.15

MDDC-388. A. H. Jaffey, T. P. Kohman and J. A. Crawford
A Manual on the Measurement of Radioactivity
OTS. PB-52739
AEC. $0.20

MDDC-403. I. Perlman
Water Problems in the Industrial Application of the Utilization of Atomic Energy
OTS. PB-50939

MDDC-538, M. Burton
Atomic Energy and Radiation Chemistry
OTS. PB-31887
AEC. $0.10

MDDC-545. A. E. Klein
Atomic Bomb Engineering
OTS. PB-31879
AEC. $0.10

MDDC-546. A. C. Klein
Engineering Features of the Atomic Bomb Plants
OTS. PB-31878
AEC. $0.10

MDDC-590. J. O. Hirschfelder and J. L. Magee
Thermodynamic Properties of Air at High Temperatures
OTS. PB-63828
AEC. $0.20

MDDC-763, G. T. Seaborg, S. G. English, V. C. Wilson and C. D. Coryell
An Introduction to Nuclear Chemistry-Lecture Series
AEC. $0.20

MDDC-792. F. C. Von der Lage
Atomic Power Engineering
AEC. $0.10

MDDC-887, H. A. Bethe and R. F. Christy
Isotopic Masses and Abundances
AEC. $0.05

MDDC-962. A. O. Allen
Effects of Radiation on Materials
AEC. $0.10

MDDC-1014. Radiation Laboratory
Course in Nuclear Physics for Engineers
AEC. $0.50

MDDC-1175. Los Alamos
Lecture Series on Nuclear Physics
Lectures 1 through 46
AEC. $0.55

MDDC-1304. M. C. Leverett
Some Engineering and Economic Aspects of Nuclear Energy
AEC. $0.10

MDDC-1497. Hanford Engineer Works
Chapter I. **Nuclear Physics Primer**
AEC. $0.15

AECD-2111. E. Segre
Segre Isotope Chart
AEC. $0.60

MonC-400. J. W. Jones and H. M. Clark
A Table of Radioactive Isotopes Arranged According to Half-lives
AEC. $0.40

(NEPA 804-LER-10). D. Cowen *et al.*
Heat Transfer Lectures
AEC. $0.90

Radiation Detection and Measuring Instruments

MDDC-282. B. C. Diven and B. Rosse
Investigation of Proportional Counters
OTS. PB-42648
AEC. $0.15

MDDC-725. L. Nierman
The Use of Hearing-Aid Type Tubes in Portable Counting-Rate Meters and Amplifiers
OTS. PB-68143
AEC. $0.10

MDDC-967. J. F. Bonner, Jr.
Alpha and Beta Ray Counters
OTS. PBL-78663
AEC. $0.25

AECD-2203. L. Wouters
Solid Counters: Scintillation Counters
AEC. $0.10

Electronic Circuits and Apparatus

MDDC-26. W. Higinbotham
Higinbotham Scale of 64, Mark 5, Model 3
OTS. PB-52719

MDDC-101. W. C. Elmore
10 Mc. Wide Band Amplifier and Scope
OTS. PB-52787
AEC. $0.15

MDDC-102. W. C. Elmore
Model 500 Amplifier
OTS. PB-52786
AEC. $0.15

MDDC-103. W. C. Elmore
Pre-amplifier—Model 500
OTS. PB-52788

MDDC-235. H. S. Bridge
Characteristics of Some Commercial Photomultiplier Tubes under Pulse Conditions
OTS. PB-52799

MDDC-475. T. M. Snyder
Theory of Ion Chambers
OTS. PB-50931
AEC. $0.10

Vacuum Engineering and Apparatus

MDDC-522. General Electric Company
Instruction-Leak Detector, Cat. No. 6933950G3
OTS. PB-60780
AEC. $0.25

MDDC-588. L. Cook
Vacuum Properties of Plastic Materials
OTS. PB-63825
AEC. $0.10

MDDC-1670. F. S. Stein and J. E. Binns
Mass Spectrometer for Leak Detection
AEC. $0.10

AECD-1814. J. W. Binns, F. S. Stein, C. R. A. Rice and S. Bashkin
Vacuum Testing at S.A.M. Laboratories
AEC. $0.15

AECD-1867. M. Dole
Behavior of the Philips Ionization Gauge in Air
AEC. $0.10

Apparatus: Valves, Seals, Pumps

MDDC-942. H. S. Bridge
Eight-inch Vacuum Pump
AEC. $1.15

MDDC-943. H. S. Bridge
Four-inch Oil Diffusion Pump
AEC. $0.75

MDDC-960. Williams
Six-inch Diffusion Pump
AEC. $0.60

MDDC-961. Wilson
Four-inch Pump Valve
AEC. $0.30

MDDC-1265. Los Alamos
Rotary Seal (Four Drawings)
AEC. $0.90

Fluorine and Fluorocarbon Production and Chemistry

MDDC-417. Author unknown
Complete Blueprints for Du Pont Carbon Fluorine Cell
AEC. $1.10

MDDC-514. E. J. Barber, L. L. Burger, and A. V. Grosse
Report on Methods for Analyzing Fluorocarbons
OTS. PB-60790

Industrial Medicine

MDDC-247. J. E. Wirth
General Rules and Procedures Concerning Activity Hazards
OTS. PB-52765
AEC. $0.15

MDDC-401. H. M. Parker
Review of Water Monitoring Procedures at Clinton Laboratories
OTS. PB-52745
AEC. $0.10

MDDC-471. H. M. Parker
Review of Air Monitoring Procedures at Clinton Laboratories
OTS. PB-52757
AEC. $0.10

MDDC-848. L. H. Hempelmann
Protection of Laboratory Personnel Handling Radioactive Materials
AEC. $0.10

MDDC-992. S. T. Cantril
Safety Rules and Procedures Concerning Activity Hazards
AEC. $0.20

MDDC-1414. P. C. Tompkins
Laboratory Handling of Radioactive Materials
AEC. $0.15

BOOKS

BOOKS RECEIVED

Constructive Uses of Atomic Energy, edited by S. C. Rothmann, Harper & Brothers, New York, 1949, 258 pages, $3.00.

Engineering Developments in the Gaseous Diffusion Process (Div. II, Vol. 16 of National Nuclear Energy Series), edited by Manson Benedict and Clarke Williams, lithoprinted by Edwards Brothers, Inc., Ann Arbor, Mich., published by McGraw-Hill Book Co., Inc., New York, 1949, 127 pages, $1.25.

OTHER LITERATURE

Unified Screw Thread Standards (National Bureau of Standards Circular 479). *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C. 30 cents.*

Atomic Energy Commission Document Sales Agency Price Lists Nos. 12 and 13. A listing of all AEC declassified and unclassified documents for sale. *Copy of price lists are available without cost from United States Atomic Energy Commission Document Sales Agency, P. O. Box 62, Oak Ridge, Tenn.*

Atomic Energy and the Life Sciences. The Sixth Semiannual Report of the AEC to Congress. *Available from Superintendent of Documents, U. S. Govt. Printing Office, Washington 25, D. C., 45 cents.*

NUCLEONIC EVENTS

REPORT ON THE ECHO LAKE COSMIC-RAY SYMPOSIUM

The University of Denver, acting as the host institution for the Inter-University High Altitude Laboratory,* in conjunction with the Office of Naval Research, the Atomic Energy Commission and the Research Corporation, sponsored a week-long Cosmic-Ray Symposium at Idaho Springs, Colorado. The meetings began on June 22 and included five days of technical discussion and two days of related activities and social events. About 100 scientists attended the symposium.

June 23 was the first day of the technical meetings. Begun in earnest at 9 a.m., they continued through the full day with Professors Carl D. Anderson and Robert Brode acting as discussion leaders. This day was devoted to a detailed discussion of the properties of mesons, including papers by R. E. Marshak, R. D. Sard, J. C. Street. J. M. Barnothy, O. Piccioni and W. B. Fretter. The day's discussion was high-lighted by an unscheduled talk by Dr. H. Yukawa on meson decay.

The next day Prof. Bruno Rossi led the discussion on "Nuclear Interaction of Cosmic Rays." Professors G. T. Reynolds, Fretter, Rossi, M. Schein and others presented recent results on stars as found in multiple-plate cloud chambers and in the photographic emulsion. Drs. B. Peters, E. P. Ney and F. Oppenheimer presented a review of interactions by heavy primary cosmic rays and gave results from recent high-altitude balloon flights. Recent findings with regard to bursts and showers were presented by Drs. K. Greisen, Cocconi, and D. J. X. Montgomery. The day's meeting was concluded with a presentation by Drs. Rossi, J. A. Van Allen and Barnothy on the cross sections for nuclear interactions.

On Saturday morning, June 25, Prof. John A. Wheeler headed a program on primary radiation, with seventeen papers comprising the morning's discussion. Dr. Wheeler presented a brief review of the influence of cosmic and terrestrial fields on cosmic rays, and was followed by Prof. E. Teller's appraisal of the current status of that new branch of science called *Magneto-hydrodynamics*, which deals specifically with the problem of the origin of cosmic rays. This new approach to the origin of cosmic rays has stimulated much theoretical work in the past year and Professors W. F. G. Swann and Peters summarized some of the recent developments in this field. The impact of these developments is being reflected in the experimental work of such groups as those at the University of Minnesota and California Institute of Technology. Professors E. Ney and H. V. Neher gave brief discussions of some of their recent data.

One of the consequences of the study of Magneto-hydrodynamics has been to focus attention on the problem of solar magnetic activity as related to cosmic rays. In this connection, Drs. Wheeler, M. S. Vallarta and D. H. Menzel discussed problems related to the solar magnetic field. A number of miscellaneous papers dealing with the primary radiation were also presented. The

* This consists of associated member institutions: The University of Chicago, Cornell University, University of Denver, Massachusetts Institute of Technology, New York University, and Princeton University.

group was then transported to Central City where Professor Byron Cohn had arranged an afternoon and evening of social activities climaxed by a group banquet at the Teller House. Dr. R. A. Millikan addressed the group on the subject of "Early Investigation in Cosmic Rays."

No formal meetings were scheduled for Sunday, June 26, but a dedication ceremony was planned for the Mount Evans Laboratory. However, because the road to the top of Mount Evans could not be cleared, the ceremony which had been planned for the summit was consummated at the base laboratory of the Inter-University High Altitude Laboratory at Echo Lake. A brief ceremony was held honoring the late Prof. Joyce C. Stearns, former University of Denver professor and host in the past to many cosmic-ray researchers at Mount Evans. Mrs. Stearns attended the ceremony together with many of Professor Stearns' lifelong friends.

On Monday the formal sessions resumed with Prof. Schein continuing the discussion of the primary radiation. Dr. Schein presented evidence on the composition of the primary radiation, and Drs. Van Allen, S. F. Singer and G. J. Perlow discussed their most recent results with regard to the cosmic-ray intensity as explored by rockets. There was considerable discussion about the directional intensity in the cosmic radiation. Prof. Neher presented a paper on the momentum distribution of the primary radiation.

On the topic of the transformations of primaries into secondaries and the origin of various components to the cosmic radiation, Prof. Schein discussed the production of nucleons and mesons, Dr. J. A. Simpson summarized results of extensive experiments on the neutron component in the atmosphere, and Prof. Swann spoke briefly on the zenith angle dependence of mesons. The day's discussion was concluded by Prof. H. A. Bethe's talk on the production and diffusion of neutrons in the atmosphere.

The final day of discussion was marked by Prof. Bethe's analysis of the theory of air-shower production. The most recent work of Dr. J. A. Blatt was considered, and Prof. Bethe gave a review of the experimental evidence supporting the present picture of the development of air showers with emphasis upon the evidence of cores (dense particle concentrations) and the lateral extension of the shower. The existence of the neutral meson was postulated in order to account for the high-energy gamma quanta required to initiate the electron-photon showers. There followed spirited discussion of the growth of a shower, its composition at various altitudes, and the evidence for charged mesons associated with extensive showers. Discussion centered about the work of Drs. Blatt and O. Piccioni. The concluding session of the day was presided over by Prof. K. Greisen and concerned experimental work with cloud chambers and Geiger counters designed to investigate the properties of air showers.

Arrangements for the conference were handled by Professors Bryon Cohn and Mario Iona of the University of Denver.

AEC NAMES ELECTRIC POWER ADVISORY GROUP

The Atomic Energy Commission has announced the establishment of a three-man temporary advisory committee to recommend ways to set up a cooperative program between the electric power industry and the AEC. The committee, whose members have been cleared for access to whatever data in the reactor field they may need to carry out the project, will review the AEC reactor development program by means of an examination of work plans and technical data, visits to principal installations, and conferences with AEC and con-

tractor representatives. It is expected that the committee will complete its review and submit its recommendations by March 31, 1950.

The members of the committee are: Philip Sporn, chairman, president of the American Gas and Electric Co.; Edward W. Morehouse, vice president of the General Public Utilities Corp.; and Walton Seymour, director of the Division of Power of the U. S. Department of the Interior.

CALIFORNIA MEDICAL SCHOOL TO GET 70-MEV SYNCHROTON

The General Electric Company will build a 70-Mev synchrotron for the University of California Medical School in San Francisco, according to a joint announcement by the Atomic Energy Commission, which will provide funds for the instrument and its operation, and the university. Scheduled for completion in 1951, the machine is said to be the first of its type to be used for research on high-energy radiation in the treatment of cancer. Robert S. Stone, professor of radiology, will direct the research program.

AEC PUBLISHING ADVISORY GROUP HOLDS FIRST MEETING

The first meeting of the temporary committee set up to advise the Atomic Energy Commission on selection of publishable material of interest to industry was held September 1 in Washington. This committee was established on a trial basis to develop a program for examining selected, potentially declassifiable information in the field of metallurgy. If this trial program proves effective, it is expected that similar methods will be applied to other fields.

The members of this committee are: Sidney Kirkpatrick, chairman, Mcgraw-Hill Book Company, Inc., New York, N. Y.; H. A. Barton, American Institute of Physics, New York, N. Y.; Gene Hardy, Chilton Publications, Inc., Washington, D. C.; Keith Henney, McGraw-Hill Publishing Company, New York, N. Y.; Edward Kreutsberg, Penton Publications, Washington, D. C.; Harry Blank, Magazines of Industry, Inc., New York, N. Y.; Walter J. Murphy, American Chemical Society, Washington, D. C.; W. A. Phair, Chilton Publications, New York, N. Y.; J. J. Smith, American Institute of Electrical Engineers, New York, N. Y.; George Stetson, American Society of Mechanical Engineers, New York, N. Y.; E. E. Thum, American Society for Metals, Cleveland, Ohio; and E. J. Van Antwerpen, American Institute of Chemical Engineers, New York, N. Y.

NYU TO GIVE NUCLEAR ENGINEERING COURSE

The graduate division of New York University College of Engineering will institute a new course called "Nuclear Energy Engineering" during the 1949–1950 academic year beginning this month, according to an announcement by Dean Thorndike Saville.

Staffs of the Chemical Engineering and Physics Departments as well as special lecturers will conduct the course. The first term will cover introduction to the field of nuclear energy from an engineering viewpoint, introduction to nuclear physics, chemistry of heavy elements and nuclear fuels, the fission process, pile theory, control and operation of a pile, design and construction of nuclear reactors, heat transfer problems, power production from nuclear reactors, safety features and disposal of radioactive wastes.

During the second term the following topics will be treated: separation processes, isotope separation and enrichment, thermal diffusion, gaseous diffusion, concentration by electromagnetic methods, preparation of heavy

water, vacuum techniques in nuclear engineering, instrumentation, and applications of nuclear engineering.

CANCER RESEARCH GRANTS, FELLOWSHIPS AVAILABLE

Applications for grants and fellowships for the period beginning July 1, 1950, are now being accepted by the Committee on Growth of the National Research Council, acting for the American Cancer Society. Applications for new grants in cancer research may be submitted until October 1.

Investigators now receiving grants will be notified individually regarding application for the extension of these grants. Final decision on applications will be made, in most cases, soon after February 1.

Fellowship applications may be submitted at any time. Those received prior to November 1 will be acted upon by the Committee on Growth in December. Those received between November 1 and March 1 will be acted upon in April. Fellowships ordinarily will begin July 1 though this date may be varied at the request of the applicant.

Communications regarding grants and fellowships should be addressed to Executive Secretary, Committee on Growth, National Research Council, 2101 Constitution Avenue, N.W., Washington 25, D. C.

PABST BREWERIES MAKES GRANT TO U. OF CHICAGO

Pabst Breweries Foundation has renewed for the fourth consecutive year a $5,000 grant for fellowships to the Institute for Nuclear Studies at the University of Chicago, according to an announcement by Chancellor Robert M. Hutchins.

One of the four national industrial organizations supporting fellowships in the university's multi-million dollar basic research program, Pabst also contributed $1,800 this year for a short-term faculty fellowship in the institute.

NUCLEAR NEWSMAKERS

Joseph B. Platt, associate professor of physics at the University of Rochester, has been given a two-year leave of absence to serve with the Atomic Energy Commission in Washington as chief of the physics branch, Research Division.

Helmut L. Bradt, currently engaged in experimental work in the fields of cosmic rays and high-energy nuclear physics at the University of Rochester, has been appointed associate professor of physics at Stanford University. He will take over his new duties next year.

George G. Manov, formerly with the radioactivity section of the National Bureau of Standards, has been appointed chief of the Advisory Field Service Branch of the AEC's Isotopes Division at Oak Ridge.

Harry Davis Bruner, head of the department of pharmacology of the University of North Carolina Medical School, has been appointed Principal Scientist in the Medical Division of the Oak Ridge Institute of Nuclear Studies.

Clifford Beck, director of the research laboratory of the Oak Ridge gaseous diffusion plant, has been appointed head of the department of physics at the University of North Carolina.

W. E. Mahin, chairman of metals research at the Armour Research Foundation of the Illinois Institute of Technology, has been named director of research.

Lawrence E. Glendenin, formerly in the department of chemistry at MIT, has joined the staff of the Chemistry Division of Argonne National Laboratory as an associate chemist.

Miles C. Leverett, former director of the technical division of the Clinton Laboratories, has been appointed technical director of the NEPA Project of Fair-

child Engine and Airplane Corp., Oak Ridge, Tenn.

E. Bruce Ashcraft, formerly at Oak Ridge National Laboratory, has been appointed manager of chemistry research for the Westinghouse atomic power division in Pittsburgh.

Paul M. Gross, vice president, dean of the graduate school, and professor of chemistry at Duke University, has been named president of the Oak Ridge Institute of Nuclear Studies. **J. Harris Purks, Jr.,** professor of physics at Emory University on leave as director of the University Center in Georgia, has been named chairman of the 24-man council of the institute. Both positions were held by **Frank P. Graham** prior to the latter's appointment to the United States Senate.

ROBERT DEXTER CONRAD (1905–1949)

Robert Dexter Conrad died on July 27, 1949, in Memorial Hospital, New York. Few scientists fully realize their debt to this single individual. Whatever worth the research program of the Office of Naval Research may have is due in great measure to his intense personality and complete understanding of the scientific method of operation. He absorbed the spirit of science and carried the torch with great forcefulness.

Captain Conrad, United States Navy, retired, was trained a naval officer. He graduated with distinction from the Naval Academy in Annapolis in June, 1927, ranking tenth in a class of 580. He was designated a Naval Constructor and graduated from the Massachusetts Institute of Technology with the degree of Master of Science in 1932. He spent the academic year of 1933–1934 at Cambridge University in England. In 1940 he was appointed Assistant Naval Attache in the American Embassy in London, England. In April, 1942, he was assigned to the Office of Coordinator of Research and Development under the Secretary of the Navy. This offered him further opportunity to broaden his acquaintance with scientists and his knowledge of science by working with all the members of the National Defense Research Committee.

In the latter stages of World War II he saw the necessity for a peacetime effort on the part of the Navy to engage in basic research. With the establishment of the Office of Research and Inventions (transferred by law without change to the Office of Naval Research) he was instrumental in establishing the working relationships between the Navy and the universities. He understood so well both the problems of the scientist and the naval officer that he was able to interpret the one to the other. As director of the Planning Division of both offices, he saw the attitude of the scientist change from skepticism to wholehearted cooperation, the attitude of the naval officer from disdain to intense interest.

The trying days following Hiroshima and Nagasaki left manifold problems for solution. The physicist wanted no part of classified research. Some narrow-minded officers wanted no release of previously classified information.

The fate of the Manhattan District and the establishment of the Atomic Energy Commission hung in the balance. In this critical period, he had the courage and ability to persuade his seniors that it was essential to maintain the research momentum of the physicists by setting up the extensive program in nuclear physics now in effect.

By far the major portion of the present research program of the ONR was established under his direction. He was on the verge of being able to enjoy the fruition of his long and tireless effort when he discovered that he was suffering from leukemia without hope of recovery. A more bitter blow would be difficult to conceive. He was retired from the Navy on July 1, 1947. He was then appointed assistant director in charge of planning of the Brookhaven National Laboratory and continued his work for science. With obvious incentive, he devoted himself, outside the laboratory, to the advancement of knowledge concerning cancer in its myriad forms. He was decisive in persuading the development of a new microscope for cancer studies. He offered to undergo any experiment conceived by the medical profession, without regard to untold pain caused thereby. Through it all he never lost his courage or his desire to advance knowledge.

His Naval honors consist of the Legion of Merit, Second Nicaraguan Medal, American Defense Medal with base clasp, European Area Medal, American Area Medal, and World War II Victory Medal.

His civilian honors are enscribed in the hearts of all his myriad friends and the cornerstones of the thousand or so research projects made possible by his efforts.

—Urner Liddel, Director, Physical Sciences Division, Office of Naval Research

---

The great advance made by Conrad in his wartime work with the Office of Naval Research was in definition of the problem involved in cancer research and in identifying with it the individual or group capable of solving it. He was able to inspire those selected with his own implicit confidence in the desirability as well as the attainability of the goal. Even more, he conveyed his conviction that its attainment was the single most important, momentous and essential thing to be desired in all the world.

To his new field, he swung an even greater conviction, determination and sense of urgency. He was satisfied that progress in medicine was impeded for lack of the aid of engineering science. He was equally convinced that engineering research would gain by the increased breadth it must derive from the contribution of some part of its scientific effort to work on biological problems.

The color translator and ultra-violet microscope developed by the Polaroid Company in collaboration with the Memorial Hospital-Sloan-Kettering Institute, the biological laboratory established at the General Electric Company, the cooperation of the Radio Corporation of America, and the Westinghouse Corporation—these are only a few examples of the accomplishment possible to a devoted mind of great vision.

The Joint Engineering Council for Medical Research was the outstanding triumph of Conrad's unique capacity for organization. From a tiny group of five friends, each a leading member of one of the great engineering societies, there grew an enthusiastic membership of scores, inspired with a brilliant concept conveyed by a tireless and generous leader.

—C. P. Rhoads, M.D., Memorial Hospital

PRODUCTS and MATERIALS

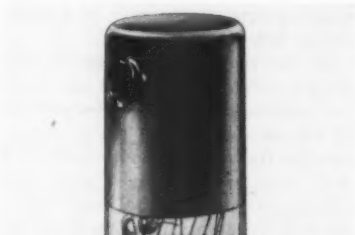
MULTIPLIER PHOTOTUBE

RCA-5819 is a head-on type of high-vacuum multiplier phototube for use in scintillation counters for the detection and measurement of nuclear particle radiation, and in other applications involving low-level, large-area light sources. This tube is manufactured by the **Radio Corporation of America, Tube Dept., Harrison, N. J.**

The spectral response of the 5819 covers the range from about 3,000 to 6,400 Angstroms. Maximum response occurs at approximately 4,800 Angstroms. The 5819, therefore, has high sensitivity to blue-rich light and negligible sensitivity to infra-red radiation. Its sensitivity to incandescent light depends on the color temperature of the source.

Design features of the 5819 include a semi-transparent cathode having a diameter of 1½ inches on the inner glass surface of the face end of the bulb, and ten electrostatically focused multiplying stages. The relatively large cathode area is designed to permit very efficient collection of light from large-area light sources, such as are encountered in scintillation counters. Because the photocurrent produced at the cathode is multiplied many times by secondary emission occurring in each of the successive dynode stages, the 5819 is capable of multiplying feeble currents produced under weak illumination by an average value of 400,000 times when operated at 90 volts per stage.

The output current of the 5819 is a linear function of the exciting illumination under normal operating conditions. Since secondary emission occurs almost instantaneously, frequency response of

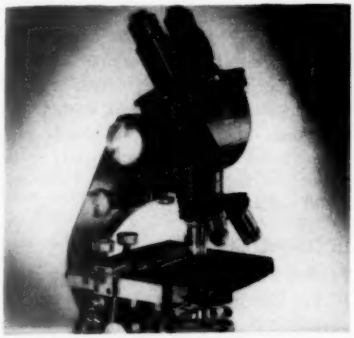


the 5819 is flat up to frequencies at which transit time and capacitance effects become the limiting factor.

In the scintillation type of nuclear radiation detector, the 5819 is particularly useful because of its large, essentially flat cathode area which permits a large optical coupling between the phosphor and the cathode. With this large coupling in combination with a suitable phosphor, it is possible to make the scintillation pulses larger in amplitude than the majority of the dark-current pulses. As a result, greater reliability of counting can be obtained.

MICROSCOPE

American Optical Co., Scientific Instrument Div., Buffalo, N. Y. A series of new AO Spencer microscopes are available. Some of the features of these instruments are: aluminum stand, an illuminator which is optional, a fork-type substage, ball-bearing ways, a



"pinch grip" mechanical stage to permit rapid insertion of slides without danger of disturbing mechanical adjustments, and a 10X divisible objective.

RADIOISOTOPE ANALYZER

Special Instruments Laboratory, Inc., 1003 Highland Ave., Knoxville, Tenn. The model 101 Autoanalyzer is a device for automatically measuring samples of radioactive materials under a variety of conditions and printing the results of the measurements on a paper

tape. Each of forty samples may be measured once with each of twelve different absorbers once per cycle and the complete cycle may be repeated continuously or for a predetermined number of times from 1 to 10.

A mica-window Geiger tube in a lead shield detects the radiation and drives a decade scaler with an electronic scale-of-100. The output from the scaler drives an electro-mechanical decade scaler, also with a scale-of-100. The total possible count is, therefore, 10,000.

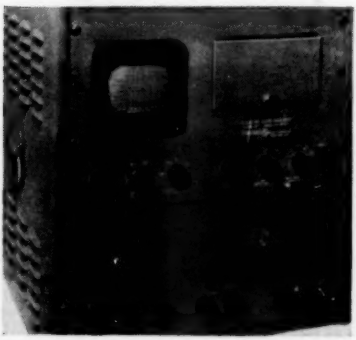
A printing timer measures and records the time required to obtain a predetermined number of counts, thus assuring the desired accuracy (probable error) on all readings in the minimum of counting time.

An automatic range selector determines the total count based on the counting rate of each sample and the type of information required. In this manner it is possible to obtain high accuracy on relatively strong samples and, at the same time, furnish the readings on weak samples within a reasonable length of time.

Samples are prepared in disposable nickel-plated steel sample holders one inch in diameter and one-quarter inch deep. As many as forty samples can be placed in the annular groove on the main turntable.

ULTRASONIC ANALYZER

Panoramic Radio Products, Inc., 10 S. Second Ave., Mt. Vernon, N. Y. The model SB-7 Ultrasonic Analyzer permits observation of one or many ultrasonic signals at one time. Indications are obtainable for signals between 2 kc and 300 kc in the form of vertical deflections distributed across a cathode-ray tube



screen, calibrated horizontally in frequency and vertically in amplitude to provide direct readings of these values.

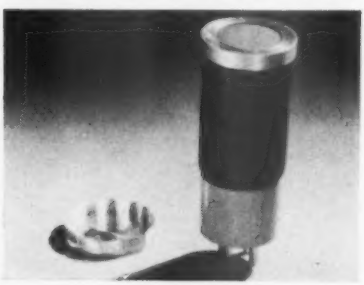
COMBINATION COUNTER

Nucleonic Corp. of America, 497 Union St., Brooklyn 31, N. Y. The model RC-1 radiation detector is designed to combine the functions of a scaling unit, a survey meter, a count-rate meter and

a contamination detector. A binary or decade scaler with a choice of scaling values is available. The count-rate meter has ranges of 500, 5,000 and 50,000 cpm. The unit has a self-contained voltage supply with a range of 500–1,600 volts. A Geiger probe for use with the instrument must be purchased separately.

THIN-MICA GEIGER COUNTER

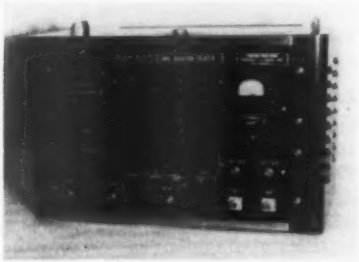
Nuclear Instrument and Chemical Corp., 223 W. Erie St., Chicago 10, Ill. This thin-mica, end-window Geiger counter is available in two models.



D31 has window thicknesses from 2–3.9 mg/cm²; and D32 is available with window thicknesses from 1.5–2.0 mg/cm². The counter, which is fitted with a standard four-prong socket, has a plateau length of 200–300 volts with a slope of 3% per hundred volts. Threshold voltage is between 1,050 and 1,300 volts.

DECIMAL SCALER

Fredric Flader, Inc., North Tonawanda, N. Y. The model 101 electronic scaling circuit is designed to count and record regularly spaced input pulses up to



100,000 per second. Special models with an upper counting limit of 1,000,000 counts per second are available. The unit will accept pulses from GM tubes or other electric or electronic counting devices.

HIGH-VOLTAGE RESISTOR

S. S. White Industrial Division, 10 E. 40 St., New York 16, N. Y. The 80X high-voltage resistor, originally developed to serve as a potential divider in an electrostatic generator at MIT, is rated at 4 watts. It is offered in values from 100 megohms to 100,000 megohms, established at 10,000 volts d-c at 75° F

and 50% relative humidity. Standard tolerance is ±10%. Lugs on the resistor are 3 in. long. The resistor body is 5/16 in. in diameter and 7⅞ in. long.

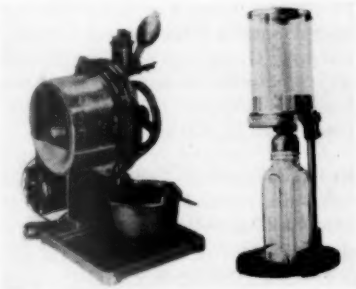
WIDE-BAND AMPLIFIER

U. S. Electronic Co., 262 Canner St., New Haven 11, Conn. The model 100 amplifier has a bandwidth extending from 4,000 cycles to 22 megacycles. The response is said to be uniform

within 3 db. Input and output connections of 75-ohm impedance are provided for use with standard coaxial cables. In addition a high-impedance output connection is available for use where required or for monitoring purposes. The amplifier has a voltage gain of 230 at average output level 0.4 volt from a 75-ohm output termination and 520 on the high-impedance output connection at 3.5-volt level.

MERCURY CLEANER

Bethlehem Apparatus Co., Front and Depot St., Hellertown, Pa. The Mercury Oxifier consists essentially of a glass drum into which the mercury is poured, with an agitator, electric motor, and



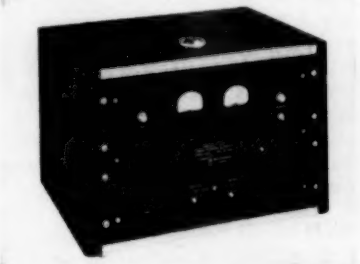
receptacle to hold the clean mercury. All the operator must normally do is flick the motor switch, and let the agitator run for several hours. The cleaning process is founded on the principle that base metal contaminations oxidize and precipitate from the mercury as metallic oxide powders.

"MAGNETIC" ADHESIVE

Union Bay State Chemical Co., 50 Harvard St., Cambridge, Mass. H-511 Ubabond is a synthetic rubber cement which is said to make possible the precementing of many materials. Described as "magnetic" in behavior, the pre-cemented surfaces can be joined together at a later time, on an assembly line or even after shipping to point of use, without loss of adhesion efficiency.

D-C POWER SUPPLY

Furst Electronics, 12 S. Jefferson St., Chicago 6, Ill. The model 1210 "twin" power supply has two independent outputs which can be used independ-



ently of each other. Each is adjustable from 0–500 volts d-c at 0–150 ma. The outputs have a common negative terminal and can give 300 ma when combined.

RADIOCHEMICAL COMPOUNDS

Tracerlab, Inc., 130 High St., Boston, Mass., has announced the availability of fifteen new radiochemical compounds tagged with carbon-14. The additions to its list are as follows: ring-labeled

toluene, ring-labeled benzoic acid, benzene, methyl-labeled sodium acetate, methyl-labeled ethyl acetate, methyl-labeled ethyl alcohol, methyl-labeled ethyl iodide or bromide, carboxyl-labeled glycine, carboxyl-labeled alanine, methylene-labeled hexoethyltetraphosphate, methylene-labeled triethylphosphate, carboxyl-labeled benzoic acid, methylene-labeled glycine, carboxyl-labeled bromoacetate, and carboxyl-labeled 2,4-D.

These compounds can be obtained directly from Tracerlab after AEC approval has been obtained. In most instances the specific activity is one millicurie per millimole.

CADMIUM TUNGSTATE

Cadmium tungstate crystals, for use as phosphors in scintillation counters, have been grown synthetically by the **Linde Air Products Co., 30 E. 42 St., New York 17, N. Y.** The crystals have a density of 7.9 and in index of refraction of 2.2 to 2.3. Cadmium tungstate's emission spectrum peaks just over 5,000 A.U., and the crystal is transparent to its own emission.

The crystals are now available only in research quantities, in ⅛ inch square section rods, in lengths up to 2 inches. These rods can be readily fabricated into windows or mosaics for scintillation counters.

HIGH-DENSITY ALLOY

P. R. Mallory and Co., Inc., Indianapolis 6, Ind. Mallory 1000 Metal is a tungsten-bearing sintered alloy of high density, approaching that of tungsten, and high strength. This material may be used as a shield or container for radium or other radioactive substances in the place of lead or platinum and gold. Since the penetrating effects of hard X-rays or gamma radiation are generally proportional to the density of the container, this material is said to be more effective than lead and less expensive than gold or platinum. It has a minimum density of 16.8 gm/cc, Young's modulus of 50,000,000 psi, and a minimum modulus of rupture of 165,000 psi.

NEUTRON SOURCES

Oak Ridge National Laboratory has developed a radioantimony-beryllium neutron source which is now available through the **Isotopes Division of the AEC at Oak Ridge, Tenn.** The sources use a core of 32 grams of antimony metal surrounded by a 3/16 in. thick beryllium metal cup, the assembly being enclosed in an aluminum jacket.

LITERATURE AVAILABLE

Catalog of Laboratory Equipment. This illustrated reference book contains information on sectional units, center tables, wall tables, fume hoods, storage cabinets and cases, combination and interchangeable units, and specialized industrial equipment. Also included is a section on laboratory layout and planning. *Metalab Equipment Corp.*, 1529 *Dean St., Brooklyn* 13, *N. Y.*

Unitized Laboratory Furniture. Description of fume hoods, cabinets, tables, storage cases and sinks. Also explains how you can be your own architect and builder in designing and installing your laboratory. *Fisher Scientific Co.*, 717 *Forbes St., Pittsburgh* 19, *Pa.*

Instruments for Measurement of Radioactivity. Gives detailed description of all products this company has available. *Radiation Counter Laboratories, Inc.*, 1844 *W.* 21 *St., Chicago* 8, *Ill.*

Radiation Counter Tubes. Gives detailed descriptions of latest models of selfquenching radiation counter tubes. *Amperex Electronic Corp.*, 25 *Washington St., Brooklyn* 1, *N. Y.*

AS MODERN AS NUCLEONICS

● Kewaunee Laboratory Furniture in wood or metal offers you every modern and time-saving convenience in fine Laboratory Equipment at prices only made possible by Kewaunee's Unit Assembly Plan. Write for Catalog.

Kewaunee
LABORATORY
FURNITURE

Representatives in Principal Cities

C. G. Campbell, President

KEWAUNEE MANUFACTURING COMPANY, 5083 S. Center St., Adrian, Mich.

toluene, ring-labeled benzoic acid, benzene, methyl-labeled sodium acetate, methyl-labeled ethyl acetate, methyl-labeled ethyl alcohol, methyl-labeled ethyl iodide or bromide, carboxyl-labeled glycine, carboxyl-labeled alanine, methylene-labeled hexoethyltetraphosphate, methylene-labeled triethyl-

PAG
MISS

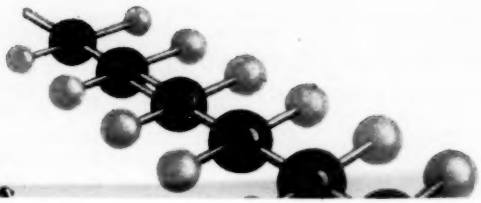
and high strength. This material may be used as a shield or container for radium or other radioactive substances in the place of lead or platinum and gold. Since the penetrating effects of hard X-rays or gamma radiation are generally proportional to the density of the container, this material is said to be more effective than lead and less expensive than gold or platinum. It has a minimum density of 16.8 gm/cc, Young's modulus of 50,000,000 psi, and a minimum modulus of rupture of 165,000 psi.

NEUTRON SOURCES

Oak Ridge National Laboratory has

all products this company has available. *Radiation Counter Laboratories, Inc.*, 1844 *W.* 21 *St., Chicago* 8, *Ill.*

Radiation Counter Tubes. Gives detailed descriptions of latest models of selfquenching radiation counter tubes. *Amperex Electronic Corp.*, 25 *Washington St., Brooklyn* 1, *N. Y.*



AS MODERN AS

GES

SING

Furniture in wood or metal offers you every modern and time-saving convenience in fine Laboratory Equipment at prices only made possible by Kewaunee's Unit Assembly Plan. Write for Catalog.

LABORATORY FURNITURE

Representatives in Principal Cities

C. G. Campbell, President

KEWAUNEE MANUFACTURING COMPANY, 5083 S. Center St., Adrian, Mich.

• *Essential reading for every scientist*

COSMIC RAY AND THE ETHERON

By Frederick M. Tschirner, Ph.D.

Here, presented for the first time, is a complete *evaluation* showing the solidarity of the universe. Based on known values, the relationship between planets, atoms, and cosmic rays are expressed mathematically.

This original cosmic concept develops and proves new facts about the nature of energy and space, including:

1) The origin of the Cosmic Ray and its function
2) A new magnitude, the Etheron
3) Bode's Fifth planet located
4) Source of the energy of point particles
5) Evaluation of the Sun-Space Volume
6) Cosmic Value of electron

This book will open new avenues to understanding the universe and the forces that control it.

ORDER YOUR COPY TODAY
The Cosmological Co.
1436 Land Title Bldg. Phila. 10, Pa.
Enclosed is Money order ☐ check ☐ for _____ copies of COSMIC RAY AND THE ETHERON at $6.00 each, post paid

Name_____

Company_____

Address_____

(*Continued from page 75*)

tage to determine the nature of artificially induced radioactivities.

4. The use of dental X-ray film to determine the energy of induced activities has only limited application, and definite limitations as to precision, but may serve in instances requiring only rough approximation.

Some practical application may be made of the process described to produce beta activities for experimental purposes in the laboratory and to translate alpha radiation to beta radiation for counting of alphas with relatively thick Geiger tube walls. In the latter application a tube with walls offering filtration of 30 to 40 mg/cm² may be wrapped with material similar to that of the covering of dental X-ray film. The induced betas can be counted after the ratio of induced beta particles to bombarding alpha particles is ascertained for the particular material used.

The RAYCHRONOMETER

A combination automatic scaling instrument and counting ratemeter for the precise and convenient measurement of radioactivity with Geiger tubes. Its many unique features are fully described in a new 8-page bulletin which is now available.

RADIOACTIVE PRODUCTS, INC.
3201 E. Woodbridge St., Detroit 7, Mich.